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Potential Water Quantity and Water Quality Impacts of Power Plant Development Scenarios on Major Rivers in the Ohio Basin

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Urbana, IL

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This report was prepared in support of the Ohio River Basin Energy Study (ORBES), a multidisciplinary policy research program supported by the Environmental Protection Agency. Water consumption levels associated with power plant cooling were estimated for different energy development scenarios for the Ohio River Basin; potential impacts of power plant consumption and pollutant emissions on ambient water quality were also estimated. Cumulative water consumption was compared to the 7-day 10-year low flow values for various locations along the tributaries and main stem of the Ohio River. The total potential consumption associated with projected municipal and non-power industrial use was also evaluated. Potential water quality impacts were estimated by assuming that constituents were conservative and were concentrated as a result of consumptive losses; this simplified approach led to useful insights.

The projected cumulative effects of power plant cooling generally appear minor (e.g., less than 10% of low flows), although in some cases the effects would be much greater. For example, Scenario 1 specifies dispersed plant locations to ameliorate air pollution impacts, but more plants are located on the smaller tributaries and the potential water quality impacts would be greater than under other scenarios. In general, potential impacts on water quality would result mainly from plant consumption; thus, such impacts would generally be small in comparison to background levels although exceptions are noted.

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ABSTRACT

Water consumption levels associated with power plant cooling were estimated for different energy development scenarios for the Ohio River Basin; potential impacts of power plant consumption and pollutant emissions on ambient water quality were also estimated. Cumulative water consumption was compared to the 7-day 10-year low flow values for various locations along the tributaries and main stem of the Ohio River. The total potential consumption associated with projected municipal and non-power industrial use was also evaluated. Potential water quality impacts were estimated by assuming that constituents were conservative and were concentrated as a result of consumtive losses; this simplified approach led to useful insights.

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FOREWORD

The Ohio River Basin Energy Study (ORBES) is an interdisciplinary, multi-university inquiry into the environmental, economic, and social impacts of energy facility development in a major portion of the Ohio River Basin. The study was initiated by the U.S. Environmental Protection Agency in 1976 in response to a directive from the U.S. Senate Appropriations Committee.

Most of the ORBES research was conducted by a group of faculty members at the University of Illinois, Indiana University, the University of Kentucky, the University of Louisville, The Ohio State University, the University of Pittsburgh, Purdue University, and West Virginia University. In a few instances, the necessary expertise was found at other universities or independent research organizations.

This report is one of a series produced in support of the overall ORBES assessment. For a summary of the entire study, see Ohio River Basin Energy Study (ORBES): Main Report, by the ORBES Core Team, also being published by the U.S. Environmental Protection Agency.

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PREFACE

This report provides information developed in a special study, "Pollutant Transport in the Waterways of the Ohio River Basin Energy Study Region in Association with Energy Conversion Facility Sitings," Project No. U.S. EPA R805-588-010, conducted as part of the Ohio River Basin Energy Study (ORBES) sponsored by the U.S. Environmental Protection Agency. The ORBES study involved many researchers from numerous universities throughout the Ohio River Basin region. Many of these researchers provided information used in our special study. Also, the products of this special study are intermediate in nature since they were prepared for use by Hugh T. Spencer from the University of Louisville; he served on the project core team and carried out the water quality impacts assessments.

In carrying out the special study and preparing this report, R. W. Fuessle was primarily responsible for Chapters 2 and 4; R. M. Lyon for Chapters 3, 5, and 6; and S. Y. Chang and R. W. Fuessle for Chapter 7. C. Fink provided valuable assistance in preparing the final report.

G. E. Stout, University of Illinois at Urbana-Champaign, and E. E. Whitlatch, III, Ohio State University also participated in the project by assisting in the design of the study and by providing information related to Illinois and Ohio, respectively.

We would like to thank the following people and agencies for supplying water resources information used in the two phases of the ORBES project: L. A. Martens, U.S. Geological Survey, Illinois; W. G. Weist, Jr., U.S. Geological Survey, Indiana; P. Emery, U.S. Geological Survey, Kentucky; J. F. Blakey, U.S. Geological Survey, Ohio; several representatives, including R. Armstrong, of the U.S. Army Corps of Engineers (Cincinnati, Louisville, and St. Louis Offices); M. Lee, and J. E. McSparran, Department of Environmental Resources, Pennsylvania; J. R. Villines and others from the Department for Natural Resources and Environmental Protection, Kentucky; and several individuals, including D. H. Schnepper and R. A. Sinclair, from the Illinois State Water Survey. We greatly appreciate information related to effluents from power plants provided by T.-Y. Chu from the Tennessee Valley Authority. Also, the following people provided useful information and suggestions related to irrigation: J. V. Mannering, Purdue University; A. W. Selders, West Virginia University; J. N. Krider, Soil Conservation Service, U.S. Department of Agriculture; and M. D. Thorne, University of Illinois at Urbana-Chamapign. We also thank E. A. Joering of the Ohio River Basin Commission for supplying information and helpful suggestions during the early stages of the project.

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE OF CONTENTS

ABSTRACT iii
FOREWORD v
PREFACE vii
TABLES xiii
FIGURES xvii

1. INTRODUCTION 1-1
    1.1 Objectives 1-1
    1.2 Procedure 1-1
    1.3 Major Observations 1-2

2. OVERVIEW OF WATER RESOURCES IN THE ORBES REGION 2-1
    2.1 Introduction. 2-1
    2.2 Precipitation and Runoff 2-1
    2.3 Inflow to the ORBES Region 2-1
    2.4 Water Sources Within the ORBES Region 2-5
    2.4.1 Streamflow 2-5
    2.4.2 Groundwater Sources and Potential Reservoir Sites . 2-5

3. WATER USE CALCULATIONS AND PROJECTIONS 3-1
    3.1 Introduction 3-1
    3.2 Municipal Water Use Projections 3-2
    3.2.1 Withdrawals 3-2
    3.2.1.1 Projection method I—per capita use 3-2
    3.2.1.2 Projection method II—municipal pumpage 3-5
    3.2.2 Consumption 3-7
    3.3 Self-Supplied Industrial Water Use Projections . . . 3-7
    3.3.1 Withdrawals 3-9
    3.3.2 Consumption 3-11
    3.4 Total (Municipal and Self-Supplied Industrial) Water Use 3-14
    3.5 Other Water Use Investigations 3-14
    3.6 Irrigation 3-18
    3.6.1 Factors Affecting Irrigation Projections 3-19
    3.6.2 Projections 3-21
    3.6.3 Water Application Rates 3-25
    3.6.4 Consumption 3-26

4. WATER CONSUMPTION UNDER DIFFERENT COOLING ALTERNATIVES . . 4-1
    4.1 Introduction 4-1
    4.2 Once-Through Cooling Systems 4-1
    4.3 Evaporative Cooling Towers 4-8
    4.4 Cooling Ponds 4-8
    4.5 Overview 4-10

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

5. WATER AVAILABILITY: A GEOGRAPHICAL ANALYSIS 5-1
  5.1 Introduction 5-1
  5.2 Major Assumptions 5-2
  5.2.1 Power Plant Water Use 5-2
  5.2.2 Scheduled Additions and Removals 5-4
  5.2.3 Municipal and Industrial Water Use 5-4
  5.2.4 Incremental Analysis and Surface Water Ratios . . . 5-5
  5.2.5 River Reaches 5-7
  5.2.6 "Updated" Impacts 5-7
  5.2.7 Ohio River Flow Data 5-8
  5.2.8 County Locations 5-8
  5.2.9 Irrigation 5-9
  5.3 Use of the Maps and Data 5-9
  5.4 Comments 5-9

6. CONSUMPTIVE IMPACTS OF ORBES SCENARIOS 6-1
  6.1 Introduction 6-1
  6.1.1 Overview of Present and Projected Water Consumption for Power Generation 6-1
  6.2 Background and Assumptions for CORT Analysis 6-5
  6.3 Plant Equivalent Scenario (No Conjured Plants) . . . 6-7
  6.3.1 Overview 6-7
  6.3.2 Illinois 6-9
  6.3.3 Indiana 6-9
  6.3.4 Kentucky 6-9
  6.3.5 Ohio, Pennsylvania and West Virginia 6-9
  6.3.6 Ohio River Main Stem 6-10
  6.4 Scenario 1 6-10
  6.4.1 Overview 6-10
  6.4.2 Illinois 6-10
  6.4.3 Indiana 6-10
  6.4.4 Kentucky 6-13
  6.4.5 Ohio 6-13
  6.4.6 Pennsylvania 6-13
  6.4.7 West Virginia 6-13
  6.4.8 Ohio River Main Stem 6-13
  6.5 Scenario 2 (Towers) 6-14
  6.5.1 Illinois 6-14
  6.5.2 Indiana 6-14
  6.5.3 Kentucky 6-14
  6.5.4 Ohio 6-14
  6.5.5 Pennsylvania 6-14
  6.5.6 West Virginia 6-14
  6.5.7 Ohio River Main Stem 6-16
  6.6 Scenario 2i (Once-Through) 6-16
  6.7 Scenario 2a (Towers) 6-16
  6.7.1 Ohio 6-16
  6.7.2 Pennsylvania 6-16
  6.7.3 Ohio River Main Stem 6-19
  6.8 Scenario 2a2 (Once-Through) 6-19
  6.9 Scenario 2b (Towers) 6-19
  6.9.1 Illinois 6-19

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
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PAGE NUMBER

EPA-287 (Cin.)
(4-76)

6.9.2 Pennsylvania 6-19
6.9.3 Ohio River Main Stem 6-19
6.10 Scenario 2b1 (Once-Through) 6-22
6.10.1 Ohio River Main Stem 6-22
6.11 Scenario 2c 6-22
6.11.1 Illinois 6-22
6.11.2 Indiana 6-22
6.11.3 Kentucky 6-22
6.11.4 Ohio 6-22
6.11.5 Pennsylvania 6-22
6.11.6 Ohio River Main Stem 6-25
6.12 Scenario 3 6-25
6.12.1 Illinois 6-25
6.12.2 Indiana 6-25
6.12.3 Kentucky 6-25
6.12.4 Ohio 6-25
6.12.5 Pennsylvania 6-25
6.12.6 West Virginia 6-27
6.12.7 Ohio River Main Stem 6-27
6.13 Scenario 4 6-27
6.13.1 Ohio River Main Stem 6-27
6.14 Scenario 5 6-27
6.14.1 Illinois 6-30
6.14.2 Ohio 6-30
6.14.3 Pennsylvania 6-30
6.14.4 Ohio River Main Stem 6-30
6.15 Scenario 6 6-30
6.15.1 Ohio River Main Stem 6-30
6.16 Summary 6-32
6.17 Error Analysis 6-32
6.17.1 Summary of Error Analysis 6-36

7. ASSESSMENT OF WATER QUALITY IMPACTS 7-1
7.1 Introduction 7-1
7.2 Estimated Background Water Quality Conditions for Scenario Assessments 7-1
7.2.1 Illinois 7-2
7.2.2 Indiana 7-9
7.2.3 Kentucky 7-9
7.2.4 Ohio 7-9
7.2.5 Pennsylvania 7-9
7.2.6 West Virginia 7-9
7.2.7 Ohio River Main Stem 7-12
7.3 Power Plant Loadings 7-12
7.3.1 Introduction 7-12
7.3.2 Ash Handling 7-12
7.3.3 Cooling Tower Blowdown 7-16
7.3.4 Scrubber Waste Flows 7-16
7.3.5 Boiler Blowdown 7-19
7.3.6 Metal Cleaning Wastes 7-19
7.3.7 Coal Pile Runoff 7-19
7.3.8 Net Pollutant Loadings from Power Plants 7-20

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3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

7.4 Methodology 7-20
7.4.1 Computational Procedure 7-20
7.4.2 Reference Standards for Water Quality 7-22
7.5 Water Quality Impacts 7-25
7.5.1 Introduction 7-25
7.5.2 Application of the Analysis Approach 7-25
7.5.3 Water Quality Analysis of Each Scenario 7-47
7.5.3.1 Scenario 2 7-47
7.5.3.2 Scenario 2a 7-50
7.5.3.3 Scenario 2b 7-51
7.5.3.4 Scenario 5 7-52
7.5.3.5 Scenario 3 7-54
7.5.3.6 Scenario 4 7-55
7.5.3.7 Scenario 1 7-56
7.5.3.8 Scenarios 21, 2a2, and 2b1
(Once-Through Cooling) 7-58
7.6 Overview 7-59

EPA-287 (Cin.)
(4-76)

TABLES

Number Page

2.1 Precipitation and Runoff in the ORBES Region 2-2

2.2 Estimated Runoff under 7-Day 10-Year Low-Flow Conditions . . . 2-3

2.3 Inflow to the ORBES Region Under Average and Low-Flow Conditions 2-4

2.4 Flows of Major Rivers in Illinois 2-6

2.5 Flows of Major Rivers in Indiana 2-9

2.6 Flows of Major Rivers in Kentucky 2-12

2.7 Flows of Major Rivers in Ohio 2-14

2.8 Flows of Major Rivers in Pennsylvania 2-17

2.9 Flows of Major Rivers in West Virginia 2-20

2.10 Flows of the Ohio River and Minor Tributaries 2-21

2.11 Selected Reservoirs in Indiana 2-23

2.12 Selected Potential Reservoirs in Kentucky 2-25

2.13 Selected Potential Reservoirs in Ohio 2-27

2.14 Selected Potential Reservoirs in Pennsylvania 2-29

2.15 Selected Potential Reservoirs in West Virginia 2-32

3.1 Municipal Water Withdrawal Projections in Million Gallons per Day 3-3

3.2 Municipal Water Consumption Projections in Million Gallons per Day 3-8

3.3 Base Year Self-Supplied Industrial Withdrawals in Million Gallons per Day 3-10

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

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9-1/8"

Number **Page**

3.4 Projected Self-Supplied Industrial Water Consumption in Million Gallons per Day 3-12

3.5 Projected Total Water Consumption in Million Gallons per Day. . 3-15

3.6 A Range of Projected Total Water Consumption Estimates for the ORBES Phase II Region in Million Gallons per Day 3-16

3.7 Projections of Irrigation in the ORBES Region 3-22

3.8 Water Consumption in 2000 for Irrigation in Comparison to Other Water Uses 3-28

4.1 Once-Through 4-2

4.2 Cooling Towers 4-3

4.3 Cooling Ponds 4-5

4.4 Spray Ponds 4-6

4.5 Water Use Coefficients for Evaluating ORBES Scenarios 4-7

5.1 Power Plant Cooling Water Figures 5-3

5.2 Reach Codes and Map Key 5-10

6.1 Present and Projected Water Consumption for Power Plant Cooling 6-2

6.2 Projected Water Consumption for Power Plant Cooling for ORBES Scenarios 6-4

6.3 Computer Files for States and Counties not in those States . . 6-6

6.4 Ratio Table for Plant Equivalent Scenario 6-8

6.5 Ohio Counties in Which Plants are Assumed to use Storage and Potential Surface Water Sources 6-11

6.6 Ratio Table for Scenario 1 6-12

6.7 Ratio Table for Scenario 2 6-15

6.8 Ratio Table for Scenario 2i 6-17

6.9 Ratio Table for Scenario 2a 6-18

6.10 Ratio Table for Scenario 2a2 6-20

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EPA-287 (Cin.)
(4-76)

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Number **Page**

6.11 Ratio Table for Scenario 2b 6-21

6.12 Ratio Table for Scenario 2b1 6-23

6.13 Ratio Table for Scenario 2c 6-24

6.14 Ratio Table for Scenario 3 6-26

6.15 Ratio Table for Scenario 4 6-28

6.16 Ratio Table for Scenario 5 6-29

6.17 Ratio Table for Scenario 6 6-31

6.18 Counties Changed to 100% Surface Water for Industrial Use . . . 6-34

7.1 Summary of Current Water Quality Conditions - Illinois 7-3
Indiana 7-4
Kentucky, West Virginia, Pennsylvania 7-5
Ohio 7-6
Ohio River 7-7

7.2 Expected Future Water Quality Problems in Illinois 7-10

7.3 Water Quality Problem Areas in Indiana 7-11

7.4 Violations of Water Quality Standards in Ohio 7-11

7.5 Violations of Water Quality Standards in Pennsylvania 7-11

7.6 Violations of Water Quality Standards for the Ohio River . . . 7-13

7.7 Chemical Effluent Guidelines and Standards for Steam Electric Power Generating Plants 7-14

7.8 Power Plant Discharges (kg/(Day · MW)). 7-17

7.9 Pollutant Loadings from Power Plants Using Existing Controls (kg/(MW·day)) 7-21

7.10 Reference Standards and Water Quality Standards in Effect in ORBES Region 7-23

7.11 Power Plant Capacity for each River under each Scenario 7-26

7.12 Summary of Water Quality Impacts under ORBES Scenarios 7-32

7.13 Comparison of Potential Concentration Increases of Ten Metals Under Four Scenarios 7-53

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

Number **Page**

7.14 Summary of New Violations of Reference Standards 7-61

7.15 Increase of TDS and SO_4 Concentrations Under 100% Loading Associated With Cooling Tower Blowdown for TDS and SO_4 7-62

MAPS

1. Illinois: Allowable Plant Equivalents under 5% Consumption Limits 5-11

2. Illinois: Allowable Plant Equivalents under 10% Consumption Limits 5-12

3. Indiana: Allowable Plant Equivalents under 5% Consumption Limits 5-13

4. Indiana: Allowable Plant Equivalents under 10% Consumption Limits 5-14

5. Kentucky: Allowable Plant Equivalents under 5% Consumption Limits 5-15

6. Kentucky: Allowable Plant Equivalents under 10% Consumption Limits 5-16

7. Ohio: Allowable Plant Equivalents under 5% Consumption Limits 5-17

8. Ohio: Allowable Plant Equivalents under 10% Consumption Limits 5-18

9. Pennsylvania: Allowable Plant Equivalents under 5% Consumption Limits 5-19

10. Pennsylvania: Allowable Plant Equivalents under 10% Consumption Limits 5-20

11. West Virginia: Allowable Plant Equivalents under 5% Consumption Limits 5-21

12. West Virginia: Allowable Plant Equivalents under 10% Consumption Limits 5-22

BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

FIGURES

Number		Page
2.1	Stream-gauging Stations in Illinois	2-8
2.2	Stream-gauging Stations in Indiana	2-11
2.3	Stream-gauging Stations in Kentucky	2-13
2.4	Stream-gauging Stations in Ohio	2-16
2.5	Stream-gauging Stations in Pennsylvania	2-18
2.6	Stream-gauging Stations in West Virginia	2-19
2.7	Water Data for Illinois	2-22
2.8	Selected Reservoir Sites in Indiana	2-24
2.9	Selected Reservoir Sites in Kentucky	2-26
2.10	Selected Reservoir Sites in Ohio	2-28
2.11	Selected Reservoir Sites in Pennsylvania	2-30
2.12	Selected Reservoir Sites in West Virginia	2-31
7.1	Major Liquid Waste Streams from a Fossil-fueled Steam Electric Power Plant (after Reference 13)	7-15
7.2	Example Summary Table of Potential Water Quality Impacts . .	7-28

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3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

INTRODUCTION

1.1 Objectives

The objectives of this special study were: 1) to determine the levels of water consumption associated with power plant cooling systems for different energy development scenarios prepared as part of the Ohio River Basin Energy Study (ORBES), and 2) to identify potential impacts of power plant consumption and pollutant emissions on water quality for the various scenarios.

This support study was an integrated part of the ORBES project. Other ORBES researchers provided input including scenario specifications and baseline water quantity and quality data for Ohio, Pennsylvania, Kentucky, and West Virginia. The products of the special study were intermediate products in that they were provided to Hugh T. Spencer of the core team who used them in preparing the water quality impacts assessments.

One activity carried out by Spencer was closely related to this project. Using water flows projected in this special study for the main stem of the Ohio River (considering all projected consumption), he obtained water quality estimates for various parameters, including dissolved oxygen and temperature from the Ohio River Valley Water Sanitation Commission (ORSANCO). These estimates were also used by Spencer in carrying out the impact assessment.

There are many water-related issues associated with energy development that were beyond the scope of this study. Such issues include the effects of acid mine drainage, thermal pollution, reservoir construction, groundwater development, air pollution on rainwater quality, and streamflow depletion on aquatic habitats. Many such issues are being examined by other ORBES researchers. There are also other factors that are interrelated with the water resources and energy systems (see, e.g., Fuessle *et al.* (1)). For instance, drastic increases in the use of water for irrigation could cause competition for water use if the combined effects of all uses would lead to unacceptable streamflow depletion under low flow conditions. There could also be additional pressure for water storage, which would lead to additional social and environmental impacts.

1.2 Procedure

Water consumption levels were compared to the 7-day 10-year low flow values for the major tributaries in the ORBES study area. The cumulative effect of all power plants located upstream of given locations in each basin were expressed as ratios of the low flow at the respective locations. In most scenarios it was assumed that new plants would employ cooling towers although

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

several scenarios specified the use of once-through cooling. The level of consumption related to municipal and non-power industrial water uses was also projected and compared to the low flow values. Assuming that all consumptive effects are cumulative implies that water lost to evaporation does not return to the Ohio Basin as streamflow; this assumption is conservative in that the levels of consumption are overestimated.

Available water supplies and projected water uses are described in Chapters 2 and 3, respectively. Water consumption levels that would result from power plant cooling systems are discussed in Chapter 4. Chapter 5 provides two sets of maps that indicate the number of power plants that can be located upstream of each reach on each river given a consumption ratio that should not be violated. One set is provided for a 5% consumption ratio, and one set for a 10% ratio. Also by using interpolation or extrapolation, the maximum acceptable number of plants can be determined for any other specified ratio.

Water quality impacts were estimated by assuming that constituents were concentrated in the water as a result of consumptive losses and by estimating the concentration increases that would result from plant waste streams. As discussed in Chapter 7, calculations were made assuming all constituents were conservative throughout the basin (detailed water quality modeling was beyond the scope of the project); this approach also leads to overestimates of the impacts since it implies that upstream discharges affect all downstream reaches equally regardless of their distance downstream. This approach was useful, however, because in many cases, these upper bounds on the total impacts in a given reach were sufficient to conclude that there would be no significant impacts in comparison to background conditions or to reference standards for the various parameters.

1.3 Major Observations

Consumptive impacts resulting from power plant cooling generally would have minor impacts throughout the region for ORBES Scenarios. The greatest potential impacts on the Ohio River would occur for Scenario 2b, and the power-related-consumption ratios would be less than 9% of the 7-day 10-year low flow. The total consumption ratios, which include municipal and industrial as well as power consumption, would be less than 14%. In the case of a low growth scenario, such as Scenario 6, the power consumption ratios are approximately 4% for the Ohio River. These ratios result mainly from planned additions as opposed to ORBES conjured plants.

The most severe potential impacts on the tributaries of the Ohio River would occur under Scenario 1, which specifies dispersed plant locations. Since 15 plants were located in areas with very limited surface supplies, it was assumed that they would require reservoirs for water storage. Environmental impacts associated with such reservoirs may be important, and must be evaluated on a case by case basis. (Such analyses were beyond the scope of this study.) Other plants specified by Scenario 1 were also located in regions with relatively small tributaries; the consumption ratios calculated for those tributaries (e.g., the Big Sandy and Little Miami) would be large (approximately 25%). The impacts of such high levels could be significant, as discussed below. By relocating these few plants, however, these potential impacts could be avoided.

The effect of substituting once-through cooling systems for cooling towers for conjured plants on the Ohio River is to reduce the projected consumption ratios somewhat. The largest decrease in the consumption ratio for the Ohio River, however, was only 1% of the 7-day 10-year low flow in comparison to the ratios obtained using cooling towers. As a result the difference in potential impacts is minor.

Water quality impacts of power plants in the ORBES scenarios would result mainly from power plant consumption and not from plant emissions, assuming new source discharge regulations and current design practices. The screening process used is as follows. Impacts were listed as significant in any case where the upper bound on the increase in concentration of a constituent would be greater than 10% or 25% of a reference standard for that constitutent selected for use in this study (see Section 7.4.2).

In most cases listed under the various scenarios, however, significant increases would be attributed to high background concentrations of particular constitutents. Power-related water consumption generally is a small portion of each 7-day 10-year low flow value. Thus, in such cases, although a potential increase might represent a significant portion of the reference standard, it would represent a much smaller increase relative to the background concentration, and the potential ecological impact could be insignificant.

In some cases analyzed, consumption ratios were large, and there would be significant increases in the concentrations of numerous constituents as a result. The most significant cases occur under Scenario 1. As an example, in one river there would be a new violation of the 500 milligram per liter (mg/l) reference standard for total dissolved solids because the background level (nearly 400 mg/l) would be concentrated as a result of a 24% consumption ratio. As noted above, most of these potential impacts could be avoided by adjustments in the locations of some of the power plants.

In general, there were very few new violations of the reference standards. Where there were new violations, the assumed background levels were often close to the standard and projected municipal and industrial consumption alone would cause the violations.

It is interesting that Scenario 1 was developed to minimize the adverse effects of power plants with respect to some air pollution problems. Plant locations were dispersed geographically; as a result more plant locations were specified for the smaller tributaries and fewer locations were specified along the main stem of the Ohio River. The water quality impacts, in many ways would be greatest under Scenario 1. As mentioned above, approximately 15 reservoirs would be required, and significant social and environmental impacts could result. Also, if plants are located along the smaller tributaries, such as the Big Sandy, there could be significant water quality impacts. This potential trade-off between air quality problems and water quality problems could present a major policy issue.

REFERENCE

1. Fuessle, R. W., R. M. Lyon, E. D. Brill, Jr., G. E. Stout, and K. E. Wojnarowski, "Power Development and Water Allocation in the Ohio River Basin," Journal of the Water Resources Planning and Management Division, ASCE 104, WRI, 1978, pp. 193-209.

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(4-76)

2. OVERVIEW OF WATER RESOURCES IN THE ORBES REGION

2.1 INTRODUCTION

The analysis of water resources is based on estimates presented below and described in more detail in a project memorandum (1). Water resources are viewed here as the sum of river inflows to the region and sources originating within the region. The inflow distinction is made because it leads to an analysis of the potential dependence (by the ORBES region) on water resources that originate outside the region.

Sources originating within the region are classified as streamflow runoff, groundwater, and potential reservoirs. Estimates of 7-day, 10-year low-flows in the major rivers are presented along with average flow data because they are commonly used in planning to represent critical periods for water quality analyses.

2.2 PRECIPITATION AND RUNOFF

Average precipitation and runoff in the ORBES region are described in Table 2.1 Runoff during low-flow conditions is defined in this study as the flow of water from the region at the boundaries. The estimates (given in Table 2.2) were made by simply summing the 7-day, 10-year discharges of the major rivers (and subtracting any inflows to the region through these rivers). The discharges of these rivers are given in a following section of this chapter. Although the low-flows do not occur simultaneously, this method was used as a conservative first approximation. Note also that some runoff is actually available for use within the region but evaporates before reaching a boundary.

2.3 INFLOW TO THE ORBES REGION

The major streams flowing into the ORBES region are listed in Table 2.3; average and 7-day, 10-year low-flows are given. As an example, the Mississippi River flow at the north-west corner of the region is an inflow since it originates outside the region. South of that point, the runoff to the Mississippi River from outside the region is estimated by the discharges of the major rivers (e.g., the Iowa River). As in the case of streamflows within the region, the 7-day, 10-year low-flows were simply summed—providing a first approximation. Note, however, that the sum of the runoff under low flow conditions (12,978 cfs from Table 2.2) plus the sum of the inflow under low flow conditions (74,600 cfs from Table 2.3) equals approximately 88,000 cfs, which is reasonably close to the 7-day 10-year low flow (approximately 94,000 cfs) of the Mississippi River below the confluence with the Ohio River.

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TABLE 2.1 PRECIPITATION AND RUNOFF IN THE ORBES REGION[1]

State	Acreage in ORBES Region	Average Annual Rainfall (in.)	Average Annual Runoff (in.)
Illinois	29,831,680	40	10[2]
Indiana	20,515,360	40	12
Kentucky	25,376,000	48	17
Ohio	21,343,360	40	12
Pennsylvania	8,823,257	41	32
West Virginia	13,161,032	48	28

[1] From Reference 2, unless otherwise indicated

[2] From Reference 3.

EPA-287 (Cin.)
(4-76)

TABLE 2.2 ESTIMATED RUNOFF UNDER 7-DAY 10-YEAR LOW-FLOW CONDITIONS

State	Total Runoff (cfs)	Rivers Included
Illinois	1500	Illinois, Kaskaskia, Big Muddy, Embarass, Little Wabash, Saline
Indiana	1700	White, Wabash
Kentucky	1400	Licking, Kentucky, Green, Big Sandy[3], Cumberland[4]
Ohio	2011	Little Miami, Great Miami, Scioto, Muskingum, Mill Creek, Beaver
Pennsylvania	5956	Allegheny, Shenango, Beaver, Clarion, Monongahela, Youghiogheny
West Virginia	411	Monongahela, Cheat, L. Kanawha, Kanawha, Guyandotte, Big Sandy
TOTAL	12,978	

[3] It was estimated that only 65% of the Big Sandy River Basin lies inside Kentucky, and 65% of the discharge was assumed to be runoff from Kentucky.

[4] Runoff from the ORBES area was estimated as follows: (low-flow at Smithland, Ky.) - (low-flow at Dover, Tenn.) + (low-flow at Rowena, Ky.).

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 2.3 INFLOW TO THE ORBES REGION UNDER AVERAGE AND LOW-FLOW CONDITIONS

River	Flows (cfs)	
Inflow to Illinois[5]	Average	7-day 10-yr
Mississippi	46910	13970
Wapsipinicon	1344	90
Iowa	6253	540
Skunk	2233	19
Des Moines	5254	124
Fox	219	0
Wyaconda	209	0
N. Fabius	249	0
Middle Fabius	211	0
S. Fabius	348	0
North	207	0
Missouri	79650	24500
Salt	1511	0
Meramac	2964	285
Rock	5237	1306
Green	528	49
Illinois	10710	2196
Subtotal	164037	43079
Inflow to Kentucky[6]		
Tennessee	67320	27900
Cumberland	13090	3010
Subtotal	80410	30910
Inflow to Pennsylvania[7]		
Allegheny	10320	470
Clarion	1448	55
Shenango	743	86
Subtotal	12511	611
TOTAL INFLOW	256958	74600

[5] From Reference 4.

[6] The average inflow of the Tennessee River is based on the average flow at Paducah (5). The 7-day 10-year low flow of the Tennessee River is calculated from the 7-day 10-year low flow of the Ohio River at Metropolis and Golconda (1) and from the flow of the Cumberland River at Smithland, Kentucky (2). Cumberland River inflow is estimated by subtracting the flow at Dover, Tennessee, from the flow at Celina, Tennessee (2).

[7] Based on Reference 2.

2.4 WATER SOURCES WITHIN THE ORBES REGION

Streamflows, groundwater sources, and potential reservoir sites in the ORBES are described below. These individual water sources are considered in the analysis of the local impacts of each ORBES scenario.

2.4.1 Streamflow

Average and 7-day, 10-year low-flows of the major rivers within the ORBES region are listed in Tables 2.4, 2.5, 2.6, 2.7, 2.8, and 2.9 (one for each state). Figures 2.1, 2.2, 2.3, 2.4, 2.5, and 2.6 show the locations of the gauging stations listed in the tables (with a few exceptions).

The Ohio River is highly regulated, and its flow characteristics must be estimated. Table 2.10 presents two sets of estimates of the 7-day, 10-year low-flow. The second set, prepared by the Corps of Engineers and used by the Ohio River Basin Commission, was used in this project. Flow data for some of the minor tributaries of the Ohio River are also given in Table 2.8.

The reader is directed to references (5, 11, 14, and 15) for additional streamflow data for the region.

2.4.2 Groundwater Sources and Potential Reservoir Sites

The major groundwater sources and potential reservoir sites in Illinois are described in Figure 2.7, a map supplied by the Illinois State Water Survey (ISWS). In particular, the water yields from these sources were estimated and are indicated on the map. Additional data describing these sources has also been published by the ISWS (reference 16).

Groundwater information for Indiana, Kentucky, Ohio, Pennsylvania, and West Virginia was obtained from references 7, 17, 18, 19, 20, and 21 and is described in a project memorandum (1). In general, the groundwater in areas adjacent to the major rivers (shown in Figures 2.2, 2.3, and 2.4) can support wells yielding 500 gallons per minute (1.1 cfs). Of course, these sources and the river flows are highly interdependent. Safe yields from the aquifers in these states are not known, and a major research need is to develop such a data base.

Potential reservoir sites for Indiana, Kentucky, Ohio, Pennsylvania, and West Virginia are described in Tables 2.11, 2.12, 2.13, 2.14, and 2.15, respectively. The approximate locations are shown in Figures 2.8, 2.9, 2.10, 2.11, and 2.12, respectively. Safe yield estimates are not available; another research need is to develop such estimates to complete the inventory of water sources in the region.

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TABLE 2.4 FLOWS OF MAJOR RIVERS IN ILLINOIS

River	Location[8]	Avg. Disch. (cfs)[9]	7-day, 10-yr low flow (cfs)[10]
Mississippi	Clinton, IA (1)	46,910	13,970
	Keokuk, IA (2)	61,100	15,170
	Alton, IL (3)	93,130	21,470
	St. Louis, MO (4)	174,000	45,970
	Chester, IL (5)	174,000	46,840
	Thebes, IL (6)	177,600	47,810
Ohio	Golconda (7)		12,610
	Metropolis (8)	262,200	44,820
Chicago Sanitary and Ship Canal	Lockport (9)	5,455	1,700
Illinois	Marseilles (10)	10,710	3,240
	Kingston Mines (11)	13,430	3,000
	Meredosia (12)	19,590	3,500
Rock	Rockton (13)	3,702	795
	Oregon (14)		1,100
	Como (15)	5,024	1,097
	Joslin (16)	5,237	1,306
Pecatonica	Freeport (17)	878	181
S. Branch Kishwaukee	DeKalb (18)		.10
Kishwaukee	Belvidere (19)	273	34.3
	Perryville (20)	568	62.3
Des Plaines	Russel (21)	104	0
	Des Plaines (22)	210	4.3
	Riverside (23)	368	18.4
Fox	Algonquin (24)	760	51
	Dayton (25)	1,506	198
DuPage	Warrenville (26)	102	13.6
	Shorewood (27)	217	45
Green	Amboy (28)		4.9
	Genesco (29)	528	49.2
Kankakee	Momence (30)	1,820	411
	Wilmington (31)	3,740	451

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EPA-287 (Cin.)
(4-76)

TABLE 2.4 CONTINUED

River	Location	Ave. Disch. (cfs)	7-day,10-yr low flow (cfs)
Iroquois	Chebanse (32)	1,583	16.6
Vermilion	Lowell (33)	722	7.3
	Pontiac (34)	374	.2
Mackinaw	Congerville (35)	435	.54
	Green Valley (36)		25.2
Spoon	Wyoming (37)		1.2
	Seville (38)	967	19
Sangamon	Monticello (39)	398	2.1
	Riverton (40)		37.2
	S. Fork at Kincaid (41)		.84
	Oakford (42)	2,929	206
LaMoine	Colmar (43)	441	.78
	Ripley (44)	739	9
Vermilion	S. Fork at Sidney (45)		13.5
	Danville (46)	927	33
Kaskaskia	Ficklin (47)		.70
	Vandalia (48)	1,401	25.7
	New Athens (49)	3,654	93
Embarass	Newton (50)		13.2
	Lawrenceville (51)		35
Little Wabash	Clay City (52)	882	.47
	Carmi (53)	2,493	5.7
Big Muddy	Mt. Vernon (54)		1.3
	Benton (55)	454	30.6
	Murphysboro (56)	1,787	35.2
Saline	Harrisburg (57)		1.1
	Junction (58)	1,211[11]	2.4[12]

---

[8] Locations of quage stations are indicated by numbers in circles on the Illinois map in Fig. 2.1.

[9] From Reference 4, unless otherwise indicated.

[10] From Reference 6, unless otherwise indicated.

[11] From Reference 7.

[12] From Reference 8.

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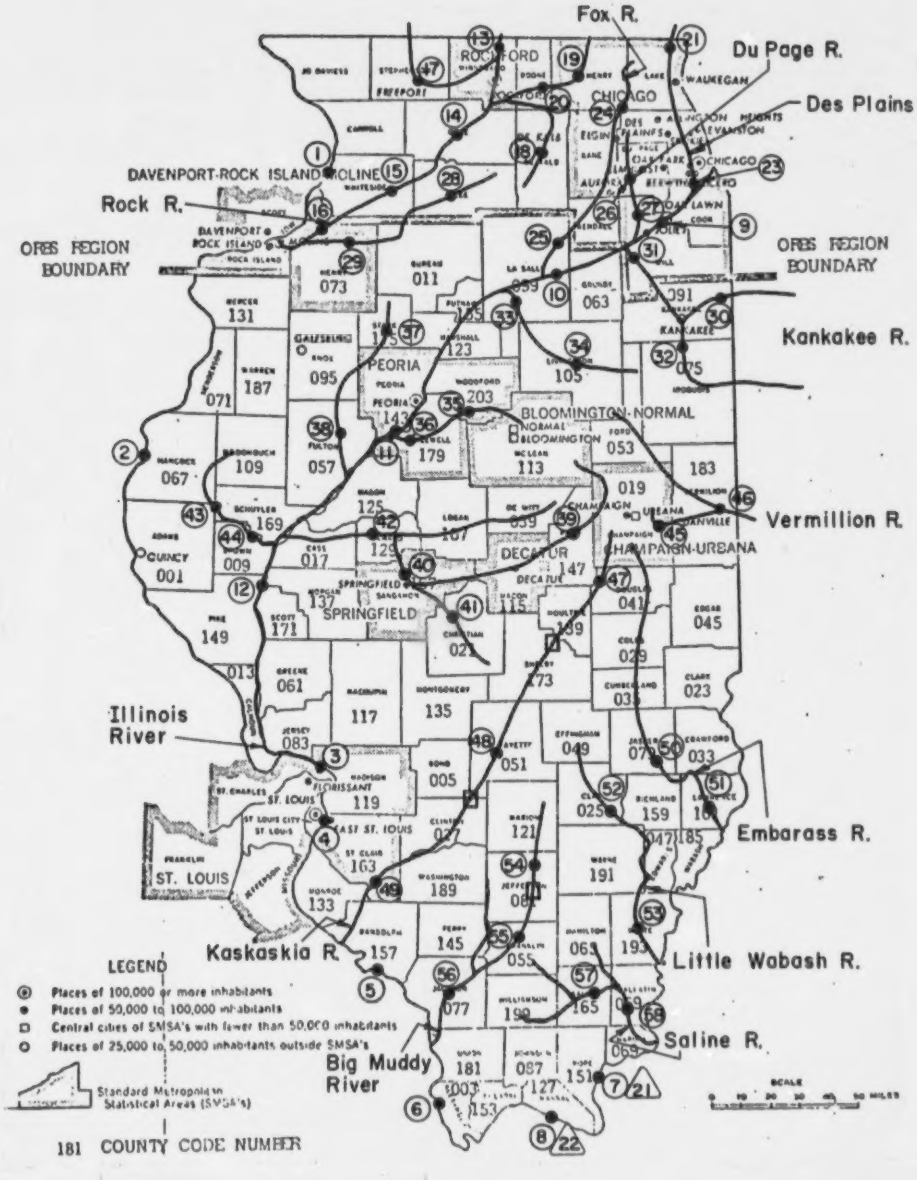
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Des Plains R.
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CHICAGO
WAUKEGAN
FREEPORT
DAVENPORT-ROCK ISLAND-MOLINE
Rock R.
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ORBES REGION BOUNDARY
Kankakee R.
PEORIA
BLOOMINGTON-NORMAL
Vermillion R.
CHAMPAIGN-URBANA
DECATUR
SPRINGFIELD
QUINCY
Illinois River
ST. LOUIS
EAST ST. LOUIS
Embarass R.
Kaskaskia R.
Little Wabash R.
Saline R.
Big Muddy River
LEGEND
Places of 100,000 or more inhabitants
Places of 50,000 to 100,000 inhabitants
Central cities of SMSA's with fewer than 50,000 inhabitants
Places of 25,000 to 50,000 inhabitants outside SMSA's
Standard Metropolitan Statistical Areas (SMSA's)
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FIGURE 2.1 STREAM-GAUGING STATIONS IN ILLINOIS

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TABLE 2.5 FLOWS OF MAJOR RIVERS IN INDIANA

River	Location[13]	Avg.Disch (cfs)[14]	7-day, 10-yr low flow (cfs)[14]
Wabash	Huntington (1)	563[15]	20[15]
	Peru (2)	2,294	87
	Logansport (3)	3,205	190
	Lafayette (4)	6,203	535
	Covington (5)	6,936	630
	Terre Haute (6)	10,200	900
	Vincennes (7)	11,240	1,060
	Mt. Carmel (46)		2,170[15]
Eel	N. Manchester (8)	347	31
	Logansport (3)	704	95
Tippecanoe	Oswego (9)	97.8	2.6
	Ora (10)	779	130
	Monticello (11)	1,451	166
	Delphi (12)	1,573	188
Mississinewa	Ridgeville (13)	125	.9
	Eaton (14)	271	2
	Marion (15)	625	16
	Peoria (16)	671	20
Salamonie	Portland (17)	64.5	.9
	Warren (18)	356	5.2
	Dora (19)	495	20
Wildcat Creek	Jerome (20)	103	1.1
	Kokomo (21)	203	8.5
	Owasco (22)	351	15
	Lafayette (4)	690	43
Big Monon Cr.	Francesville (23)	135	10
Vermilion	Danville (24)	889	12.8
	Catlin (25)		11.2
Sugar Cr.	Crawfordsville (26)	458	4.4
	Byron (27)	624	19
Big Raccoon Cr.	Fincastle (28)	122[15]	2[15]
	Coxville (29)	438[15]	30[15]

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TABLE 2.5 CONTINUED

River	Location	Avg. Disch (cfs)	7-day, 10-yr low flow (cfs)
White	Anderson (30)	367	36
	Noblesville (31)	801	61
	Indianapolis (32)	1,344[15]	44[15]
	Near Centerton (33)	2,271[15]	208[15]
	Spencer (34)	2,971	210
	Newberry (35)	4,490	275
	Petersberg (36)	11,230	685
Fall Cr.	Fortville (37)	161	14
Eagle Cr.	Zionsville (38)	91.3	0
Eel	Bowling Green (39)	825	17
E. Fork White	Columbus (40)	1,786	100
	Seymour (41)	2,346	155
	Bedford (42)	3,438	182
	Shoals (43)	5,289	222
Muscatatack	Deputy (44)	337	0
Vernon Fk.	Vernon (45)	215	0

[13] Locations are indicated by numbers in circles on the Indidana map in Fig. 2.2.
[14] From Reference 7, unless otherwise indicated.
[15] From Reference 9.

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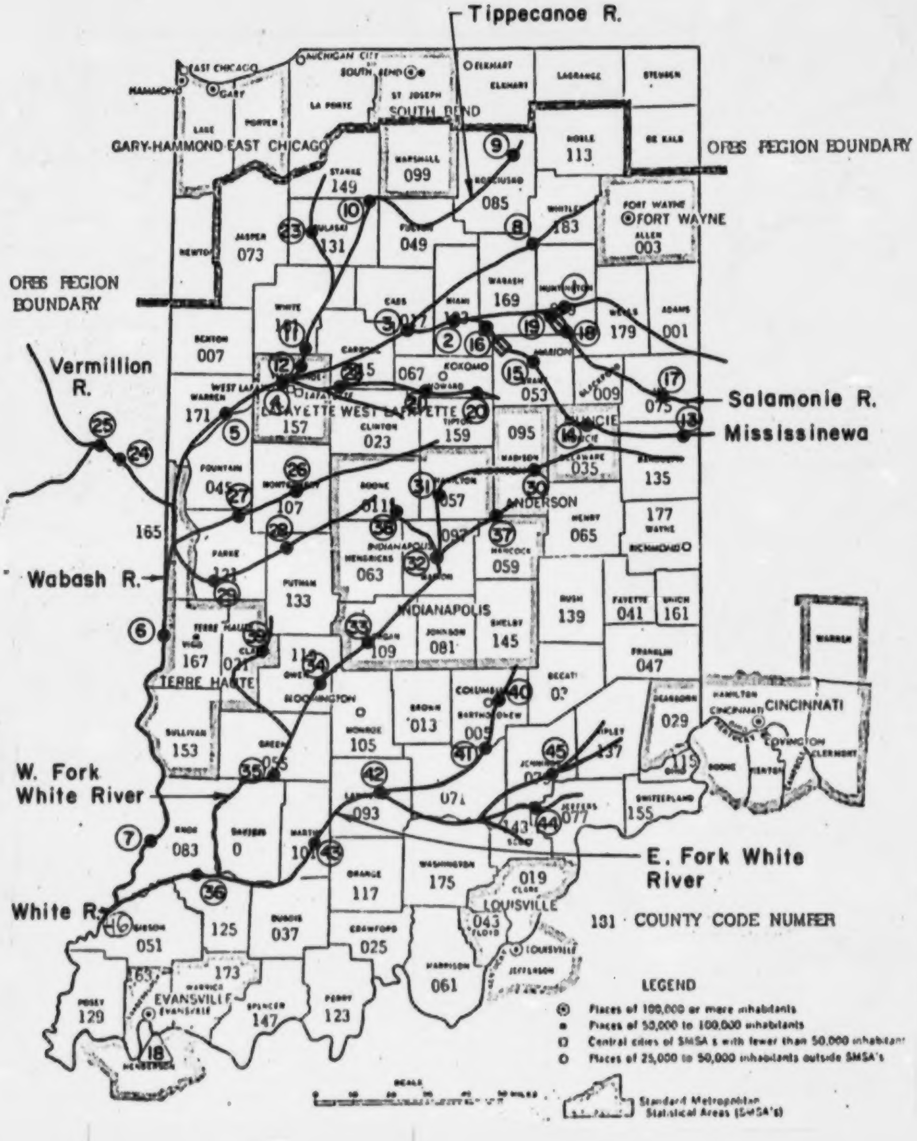
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Salamonie R.
Mississinewa
LAFAYETTE-WEST LAFAYETTE
MUNCIE
ANDERSON
Wabash R.
INDIANAPOLIS
TERRE HAUTE
CINCINNATI
W. Fork White River
E. Fork White River
White R.
LOUISVILLE
EVANSVILLE
131 COUNTY CODE NUMBER
LEGEND
Places of 100,000 or more inhabitants
Places of 50,000 to 100,000 inhabitants
Central cities of SMSA's with fewer than 50,000 inhabitants
Places of 25,000 to 50,000 inhabitants outside SMSA's
Standard Metropolitan Statistical Areas (SMSA's)

FIGURE 2.2 STREAM-GAUGING STATIONS IN INDIANA

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TABLE 2.6 FLOWS OF MAJOR RIVERS IN KENTUCKY

River	Location[16]	Avg. Disch.(cfs)[17]	7-day, 10-yr low flow (cfs)[17]
Kentucky	Winchester (1)	5,223	33
	Frankfort (2)	7,023	112
	Lockport (3)	8,247	163
	N. Fork at Hazard (10)		1.5
	N. Fork at Jackson (11)	1,293	2.2
	S. Fork at Booneville(12)	1,028	
	Middle Fork at Talega (13)	700	
	Elkhorn Cr.Nr. Frankfort (14)	599	
Salt	Shepherdsville (4)	1,533	
Rolling Fork	Boston (5)	1,720	1.3
Licking	Farmers (6)	1,076	3.1
	McKinneysburg (7)	3,038	
	Catawba (8)	4,131	10
	S. Fork at Cynthiana (9)	751	.7[18]
Green	Greensburg (15)	1,086	1.7
	Brownsville (16)	4,136	141
	Woodbury (17)	7,979	241
	Livermore (18)	10,850	306
Barren	Bowling Green (19)	2,464	53
Rough	Dundee (20)	963	11.1
Cumberland	Barbourville (21)	1,722	8.3
	Williamsburg (22)		8.6
	Cumberland Falls (23)	3,146	16
	S. Fork at Stearns (24)	1,767	
Tradewater	Olney (25)	328	0[18]
Big Sandy	Louisa (26)	4,228	59
	Levisa Fk. at Pikesville (27)	1,353	3.9
	Levisa Fk. at Paintsville (28)	2,385	15
L. Sandy	Grayson (29)	484	2.7

[16] Locations are indicated by numbers in circles on the Kentucky may in Fig. 2.3.

[17] From Reference 2, unless otherwise indicated.

[18] The low-flow for the Licking was obtained from Reference 10, and the low-flow for the Tradewater was obtained from Reference 8.

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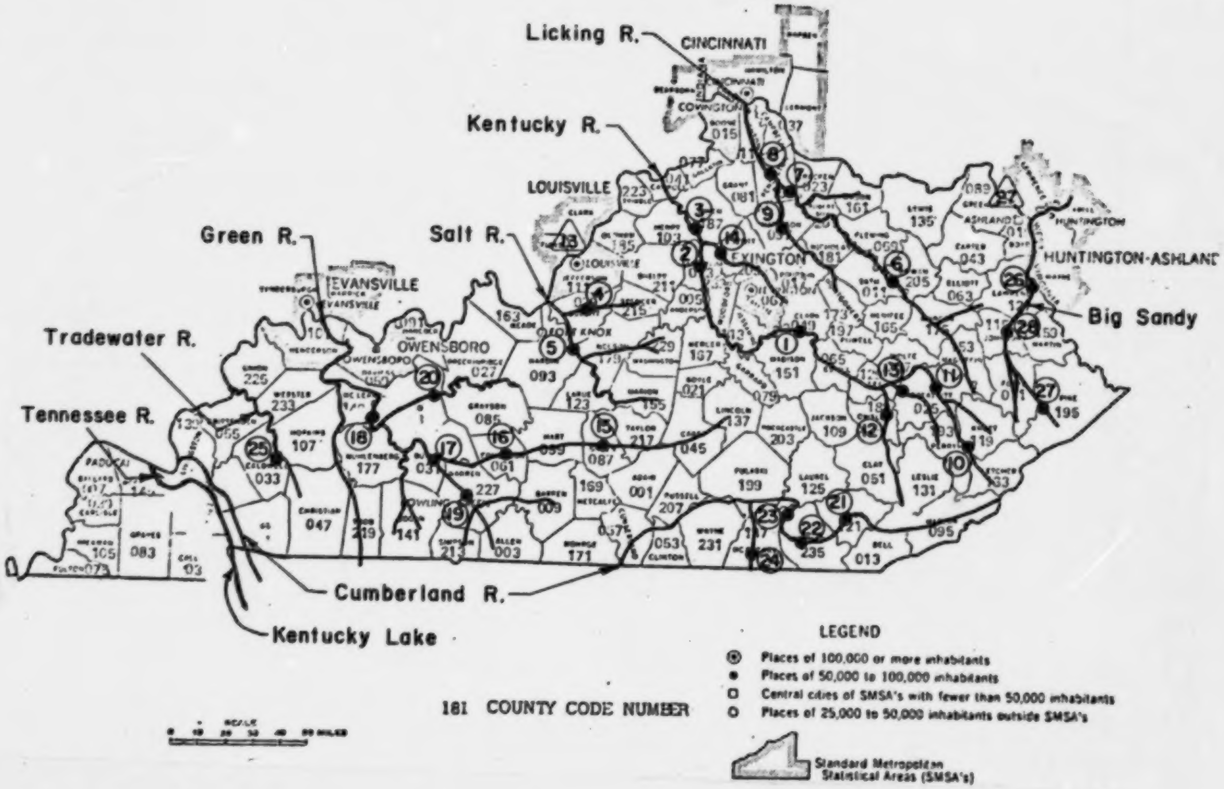
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OWENSBORO
Tradewater R.
Tennessee R.
PADUCAH
HUNTINGTON-ASHLAND
Big Sandy
Cumberland R.
Kentucky Lake
181 COUNTY CODE NUMBER
LEGEND
Places of 100,000 or more inhabitants
Places of 50,000 to 100,000 inhabitants
Central cities of SMSA's with fewer than 50,000 inhabitants
Places of 25,000 to 50,000 inhabitants outside SMSA's
Standard Metropolitan Statistical Areas (SMSA's)
SCALE
0 10 20 30 40 50 MILES

FIGURE 2.3. STREAM-GAUGING STATIONS IN KENTUCKY

TABLE 2.7 FLOWS OF MAJOR RIVERS IN OHIO

River	Location[19]	Avg. Disch. (cfs)[20]	7-day,10-yr low flow (cfs)[21]
Little Miami	Milford (1)	1,205	45
	E. Fork at Perinton(2)	547	1.0
	Oldtown (3)	107[22]	7.3
	Caesar Creek, Harveysburg (4)	210[22]	.2
	Caesar Creek, Wellman (5)	235[22]	1.3
	Todd Fk, Roachester (6)	224[22]	.2
	E. Fork, Williamsburg (7)	277[22]	0
	E. Fork, Batavia (8)	415[22]	.4
Mill Creek	Carthage (9)		4.2
Great Miami	Sydney (10)	473	18[20]
	Taylorsville (11)	995	46[20]
	Dayton (12)	2,083	175[20]
	Miamisburg (13)	2,295	223[20]
	Hamilton (14)	3,203	281[20]
Mad	Urbana (15)	140	33[20]
	Springfield (16)	481	115[20]
Stillwater	Englewood (17)	571	12[20]
Whitewater	Alpine, IN (18)	545	45
	Brookville, IN (19)	1,274	82
	E. Fork at Brookville, IN (19)	423	19
Scioto	Columbus (20)	1,336	41
	Circleville (21)	3,294	128
	Chillicothe (22)	4,370	147
	Mouth of the Scioto (23)	4,370	600
Big Walnut Creek	Rees (24)	487	7
Big Darby Creek	Darbyville (25)	438	6.2
Olentangy	Delaware (26)	Reliable records not available due to Delaware Reservoir.	
	Prior to Delaware Reservoir construction	348	1
Paint Creek	Bourneville (27)	788	7.8

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TABLE 2.7 (CONTINUTED)

River	Location	Avg. Disch. (cfs)	7-day,10-yr low flow (cfs)
Muskingum	Coshocton (28)	4,855	464
	Zanesville (29)	6,926	550
	McConnelsville (30)	7.282	565
	Mouth of Muskingum (23)		790
Tuscarawas	Dover (31)	1,375	159
	Newcomerstown (32)	2,422	210
Walhonding	Nellie (33)	1,457	
Mohican	Green (34)	879	
Licking	Tobosco (35)	672	50
Nimishillen Cr.	N. Industry (36)	166	23[19]
Mohoning	W. Branch at Newton Falls (37)	98.7	4.1[20]
	Youngstown (38)	844	200
	Lowellville (39)	1,078	290

[19] Locations are indicated by numbers in circles on the Ohio Map in Fig. 2.4.
[20] From Reference 2, unless otherwise indicated.
[21] From Reference 8, unless otherwise indicated.
[22] From Reference 11.

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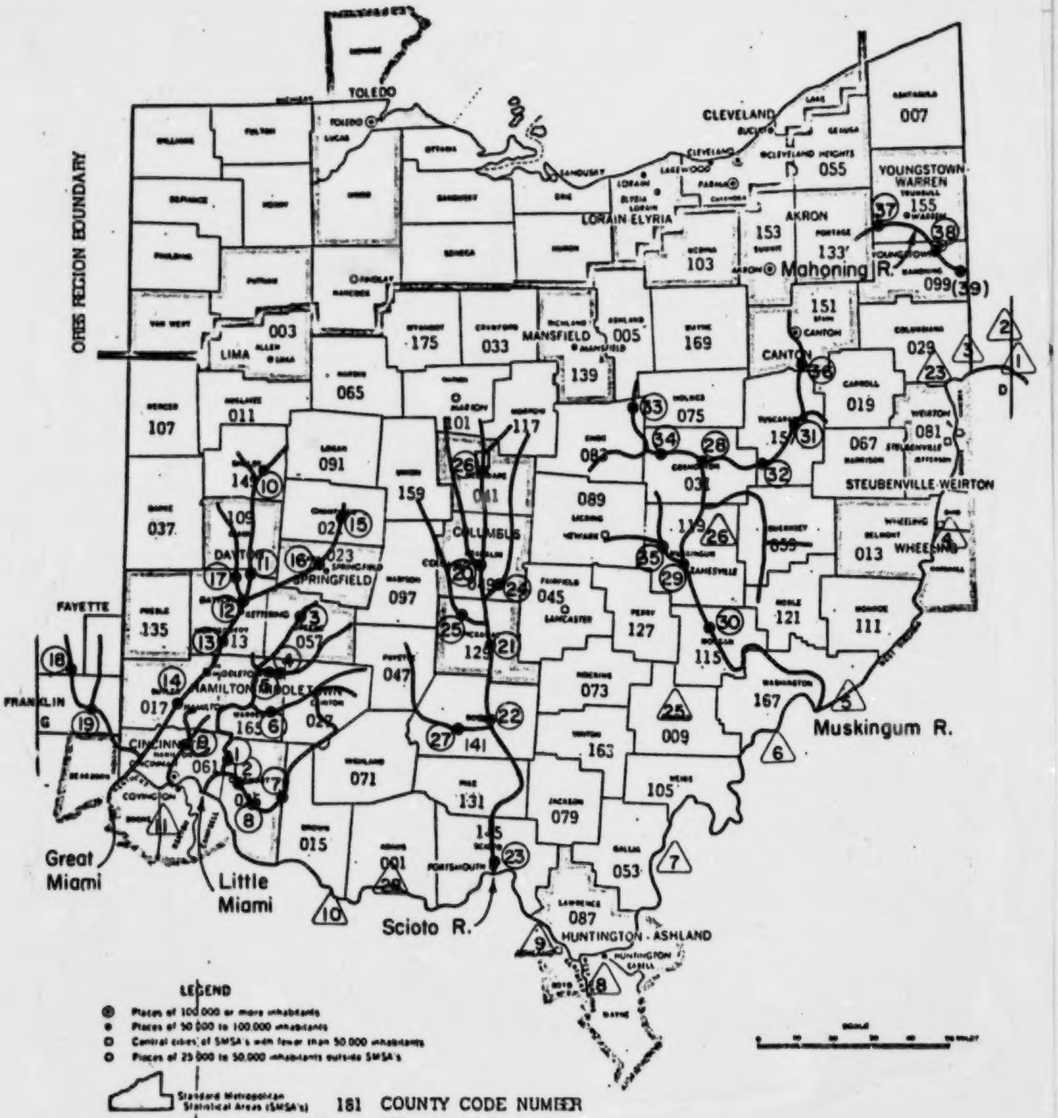
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CINCINNATI
STEUBENVILLE-WEIRTON
WHEELING
HUNTINGTON-ASHLAND
FAYETTE
FRANKLIN
OHIO REGION BOUNDARY
Great Miami
Little Miami
Scioto R.
Muskingum R.
LEGEND
Places of 100,000 or more inhabitants
Places of 50,000 to 100,000 inhabitants
Central cities of SMSA's with fewer than 50,000 inhabitants
Places of 25,000 to 50,000 inhabitants outside SMSA's
Standard Metropolitan Statistical Areas (SMSA's)
181 COUNTY CODE NUMBER

FIGURE 2.4. STREAM-GAUGING STATIONS IN OHIO

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TABLE 2.8 FLOWS OF MAJOR RIVERS IN PENNSYLVANIA

River	Location[23]	Avg. Disch. (cfs)[24]	7-day,10-yr low flow (cfs)[24]
Allegheny	Franklin (1)	10,320	470
	Kittaning (2)	15,710	750
	Natrona (3)	19,490	1,096
Clarion	Cooksburg (4)	1,448	55
Kiskimenatas	Vandergrift (5)	3,032	220
Conemaugh	Tunnelton (6)	2,352	234
French Cr.	Utica (7)	1,733	
Monongahela	Greensboro (8)	8,168	384
Youghiogheny	Connellsville (9)	2,503	75
Shenango	Sharpsville (10)	743	86
Beaver	Wampum (11)	2,365	232
Susquehanna	Curwensville (12)	605[25]	27[25]
	Karthaus (13)	2,470[25]	135[25]

---

[23] Locations are indicated by numbers in circles on the map of the ORBES region in Pennsylvania, Fig. 2.5.

[24] Reference 2, unless indicated. For Ohio River discharge estimates, see Flows of the Ohio River and Minor Tributaries, p. 2-17.

[25] From Reference 12.

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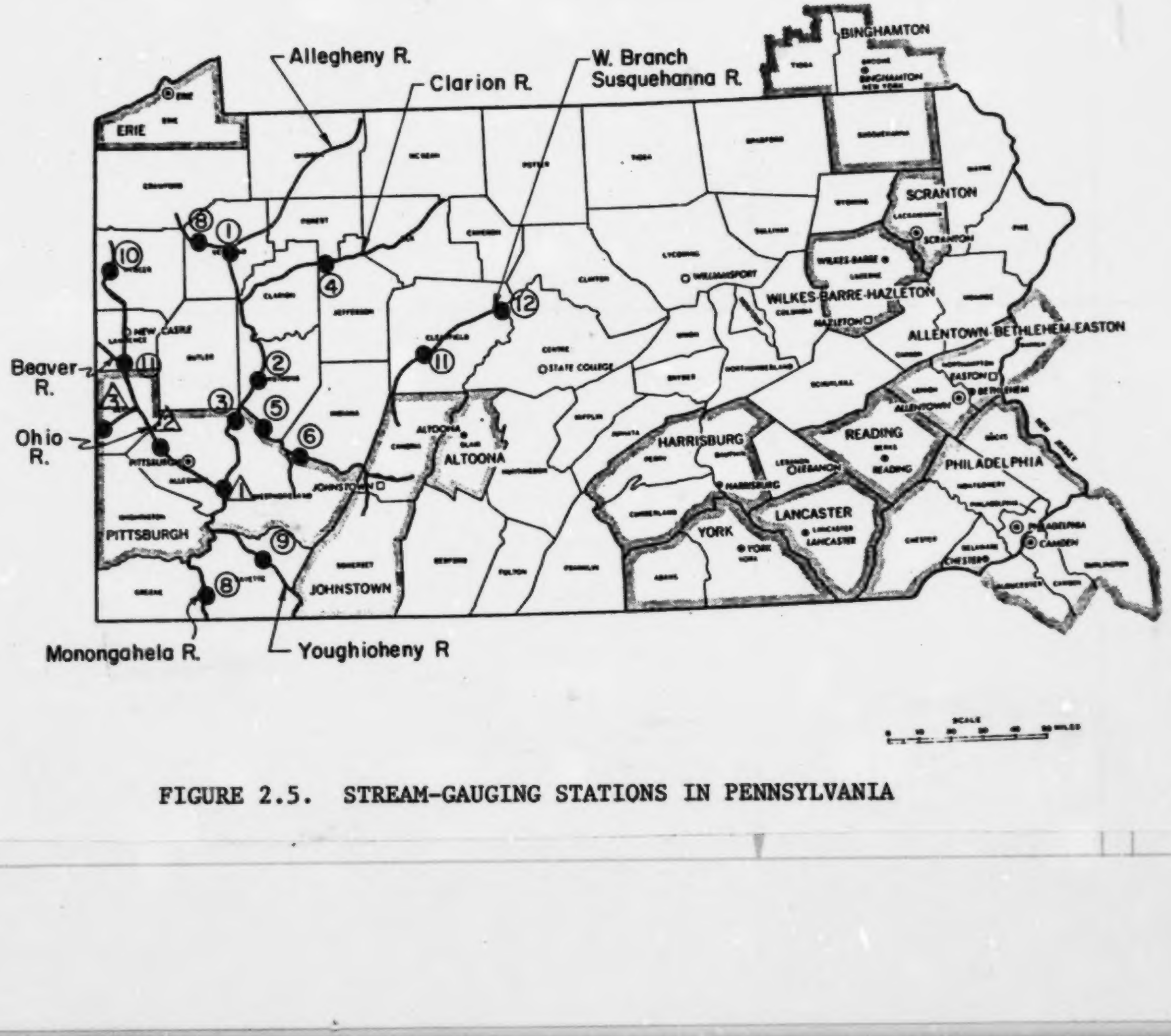
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READING
PHILADELPHIA
ALLENTOWN-BETHLEHEM-EASTON
WILKES-BARRE-HAZLETON
SCRANTON
BINGHAMTON
NEW CASTLE
SCALE
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FIGURE 2.5. STREAM-GAUGING STATIONS IN PENNSYLVANIA

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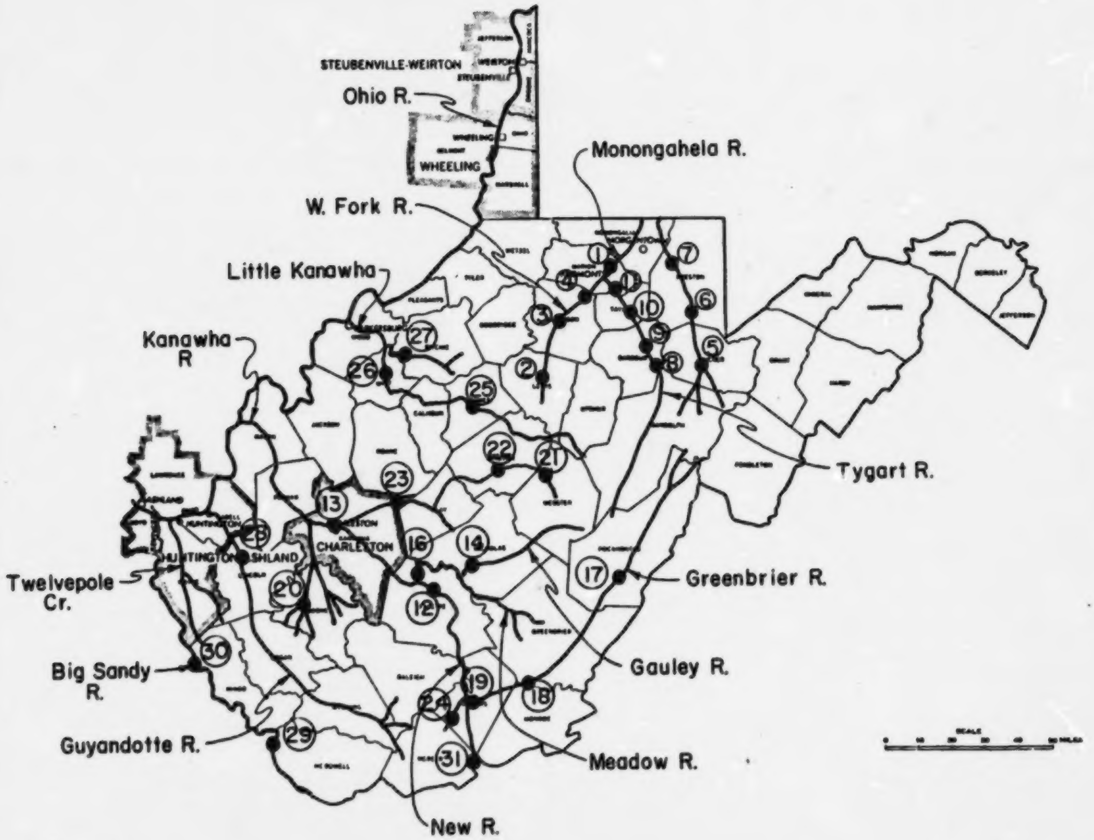
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Tygart R.
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ASHLAND
CHARLESTON
Twelvepole Cr.
Greenbrier R.
Big Sandy R.
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FIGURE 2.6. STREAM-GAUGING STATIONS IN WEST VIRGINIA

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TABLE 2.9 FLOWS OF MAJOR RIVERS IN WEST VIRGINIA

River	Location[26]	Avg. Disch. (cfs)[27]	7-day,10-yr low flow (cfs)[27]
Monogahela	Hoult (1)	4,120	99
West Fork	Gutchersville (2)	305	.2
	Clarksburg (3)	599	2.3
	Enterprise (4)	1,170	11
Cheat	Parsons (5)	1,656	33
	Rowlesburg (6)	2,222	
	Pisgah (7)	2,988	
Tygart	Belington (8)	798	4.2
	Phillipi (9)	1,824	8
	Grafton (10)	2,294	170
	Colfax (11)	2,607	192
Kanawha	Kanawha Falls (12)	12,580	
	Charleston (13)	10,367	1,285
Gauley	Summersville (14)	1,536	5.5
	Belva[2] (15)	2,633	12
	at mouth (16)		13
Greenbrier	Buckeye(17)	847	11
	Alderson (18)	1,993	42
	Hilldale (19)	2,152	56
Little Coal	Danville (20)	337	
Elk	Centralia (21)	650	3.7
	Sutton (22)	1,094	4
	Queen Shoals (23)	1,951	6.2
Bluestone	Pipestem (24)	466	
Little Kanawha	Glenville (25)	601	
	Palestine (26)	2,100	3.5
Hughes	Cisco (27)	435	
Guyandotte	Branchland (28)	1,573	20
Tug Fk.	Litwar (29)	529	21
	Kermit (30)	1,332	26
New R.	Glenlyn (31)	4,929	1,050

---

[26] Locations are indicated by numbers in circles on the West Virginia map in Fig. 2.6.

[27] Reference 2, unless otherwise indicated.

TABLE 2.10 FLOWS OF THE OHIO RIVER AND MINOR TRIBUTARIES

River	Location[28]	Avg. Disch (cfs)[29]	7-day,10-yr Low flow Estimates (cfs)[30]	7-day,10-yr Low flow Estimates (cfs)[31]
Ohio	Pittsburgh, PA (1)		3,100	6,555
	Sewickley, PA (2)	32,740	3,100	
	Ohio-PA State line (3)		3,600	
	Wheeling, W.Va. (4)		3,700	6,820
	St. Marys, W.Va.(5)		4,000	
	Parkersburg, W.Va. (6)	50,730	4,900	8,055
	Pt. Pleasant, W.Va. (7)		6,600	
	Huntington, W.Va. (8)	77,620	6,900	9,950
	Ashland, KY (9)		7,400	
	Maysville, KY (10)	91,550	7,800	11,150
	Cinn., OH (11)	96,810	7,900	12,130
	above Kentucky R.(12)		8,100	
	Louisville, KY (13)	113,700	8,200	14,265
	Dam 43 (14)		8,800	
	Dam 45 (15)		9,100	
	Dam 46 (16)		9,200	
	Dam 47 (17)		9,300	
	Evansville, IN (18)	133,900	11,000	16,635
	Dam 48 (19)		11,000	
	Dam 49 (20)		11,000	
	Golconda, IL (21)		14,000	
	Metropolis, IL (22)	258,500	46,000	47,230
Little Beaver	E. Liverpool,OH (23)	522	18	
Hocking	Enterprise, OH (24)	435	29	
	Athens, OH (25)	978	43	
Raccoon Cr.	Adamsville, OH (26)	655	3.4	
Tygarts Cr.	Greenup, KY (27)	304	.2	
Ohio Bush Cr.	West Union, OH (28)	442	.2	
Mill Cr.	Carthage, OH (20)		4.2	
Blue	Whitecloud, IN(30)	617	12	

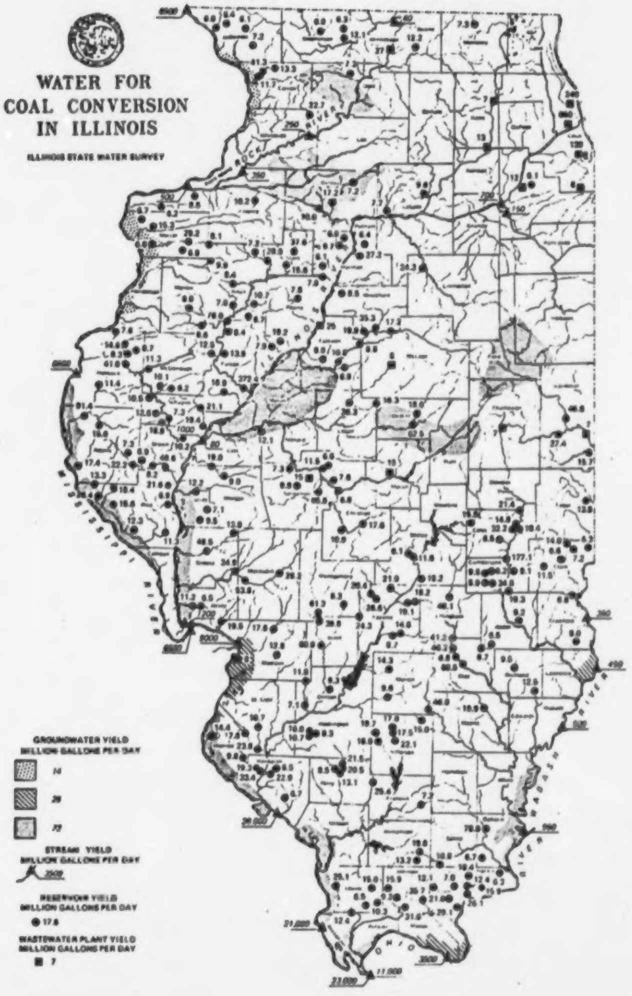
---

[28] Locations are indicated by numbers and triangles on Figs. 2.1, 2.2, 2.3, 2.4, 2.5, and 2.6.

[29] From Reference 2.

[30] From Reference 8.

[31] From Reference 13.


WATER FOR
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IN ILLINOIS
ILLINOIS STATE WATER SURVEY
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14
28
72
STREAM YIELD
MILLION GALLONS PER DAY
2500
RESERVOIR YIELD
MILLION GALLONS PER DAY
17.6
WASTEWATER PLANT YIELD
MILLION GALLONS PER DAY
7
OHIO

Stream Yield = Minimum daily flow once in 50 years.
Reservoir Yield = 1/2 the capacity during a once-in-40-years drought.

FIGURE 2.7. WATER DATA FOR ILLINOIS

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TABLE 2.11 SELECTED RESERVOIRS IN INDIANA[32]

Location No.[33]	Reservoir[34]	Drainage Area (sq. mi.)	Total Storage (ac-ft)
1	Mississinewa (E)	807[35]	368,400
2	Salamonie (E)	553	263,600
3	Huntington (E)	717[35]	153,100
4	Cecil M. Hardin (E)	216	133,000[35]
5	Cagles Mill (E)	293[35]	228,000[35]
6	Monroe (E)	432[35]	446,000[35]
7	Big Blue (P)	269	85,700
8	Downeyville (P)	276	86,400
9	Patoka (E)	168	301,600
10	Azalia (P)	250	69,920
11	Deputy (P)	294	147,000
12	Parker (P)	175	133,000
13	Maltersville (P)	62	23,200
14	Upper Martinsville (P)	2,110	420,000
15	Deer Creek (P)	280	90,000
16	Denver (P)	680	263,000
17	Pipe Creek (P)	167	68,800
18	Delphi, Upper (P)	4,136	514,000
19	Coal Creek (P)	256	170,250
20	Big Walnut (P)	197	160,700

[32] Reference 7, unless otherwise indicated.
[33] Locations are indicated by number on state map in Fig. 2.8.
[34] Potential (P) or existing (E).
[35] From Reference 9.

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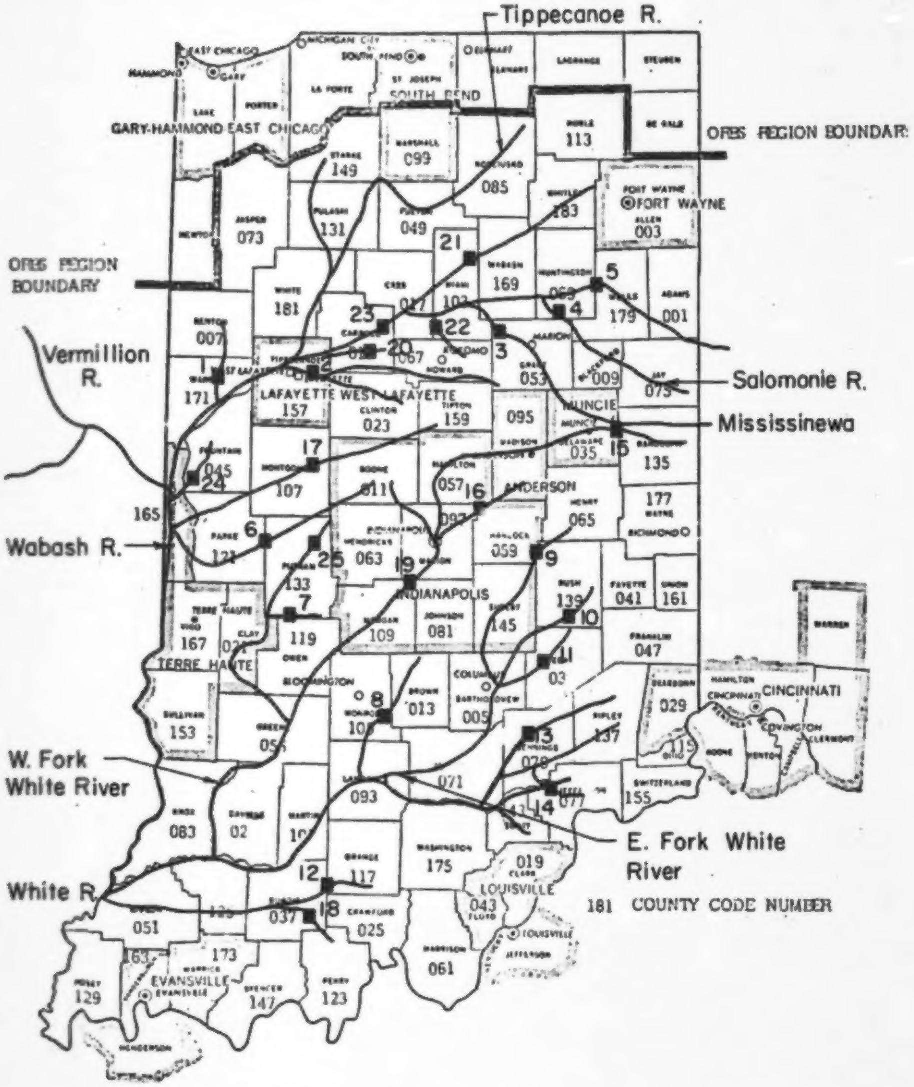
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GARY
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SOUTH BEND
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LAGRANGE
STEUBEN
LAKE
PORTER
LA PORTE
ST JOSEPH
SOUTH BEND
GARY-HAMMOND EAST CHICAGO
NOBLE
113
DE KALB
ORBES REGION BOUNDARY
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MARSHALL
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KOSCIUSKO
085
FORT WAYNE
FORT WAYNE
WHITLEY
183
ALLEN
003
NEWTON
JASPER
073
PULASKI
131
FULTON
049
21
WABASH
169
ORBES REGION BOUNDARY
WHITE
181
CASS
017
MIAMI
103
HUNTINGTON
069
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4
WELLS
179
ADAMS
001
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WEST LAFAYETTE
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CINCINNATI
COVINGTON
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153
GREENE
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JENNINGS
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RIPLEY
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KENTON
CLERMONT
W. Fork White River
LAWRENCE
093
071
JACKSON
SWITZERLAND
155
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KNOX
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DAVIESS
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MARTIN
101
SCOTT
E. Fork White River
12
ORANGE
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WASHINGTON
175
019
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LOUISVILLE
White R.
051
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CRAWFORD
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FLOYD
181 COUNTY CODE NUMBER
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WARRICK
EVANSVILLE
EVANSVILLE
SPENCER
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PERRY
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HARRISON
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HENDERSON
WARREN

FIGURE 2.8. SELECTED RESERVOIR SITES IN INDIANA

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TABLE 2.12 SELECTED POTENTIAL RESERVOIRS IN KENTUCKY[36]

Location No.[37]	Reservoir	Drainage Area (sq. mi.)	Total Storage (ac-ft)
1	Drakes Creek	500	307,000
2	Camp Ground	438	448,600
3	Floyds Fork	42	139,500
4	Howardstown	384	369,300
5	Taylorsville[38]	354	399,100
6	Cutshin Creek	84	69,000
7	Ford	2,503	840,000
8	Greasy Creek	51	30,200
9	Kingdom Come	131	73,000
10	Leatherwood Creek	49	35,000
11	Line Fork	64	62,000
12	Little Goose Creek	38	30,000
13	Red Bird River	115	90,000
14	Station Camp Creek	95	290,000
15	Troublesome Creek	201	112,000
16	Walkers Creek	1,260	180,500
17	Falmouth	1,505	898,300
18	Hinkston Creek	174	128,000
19	Royalton	76	47,300
20	Paintsville[36]	92	76,400
21	Yatesville[36]	208	99,800

[36] Reference 2.
[37] Locations are indicated by number in State Map in Fig. 2.9.
[38] Under construction, Reference 13.

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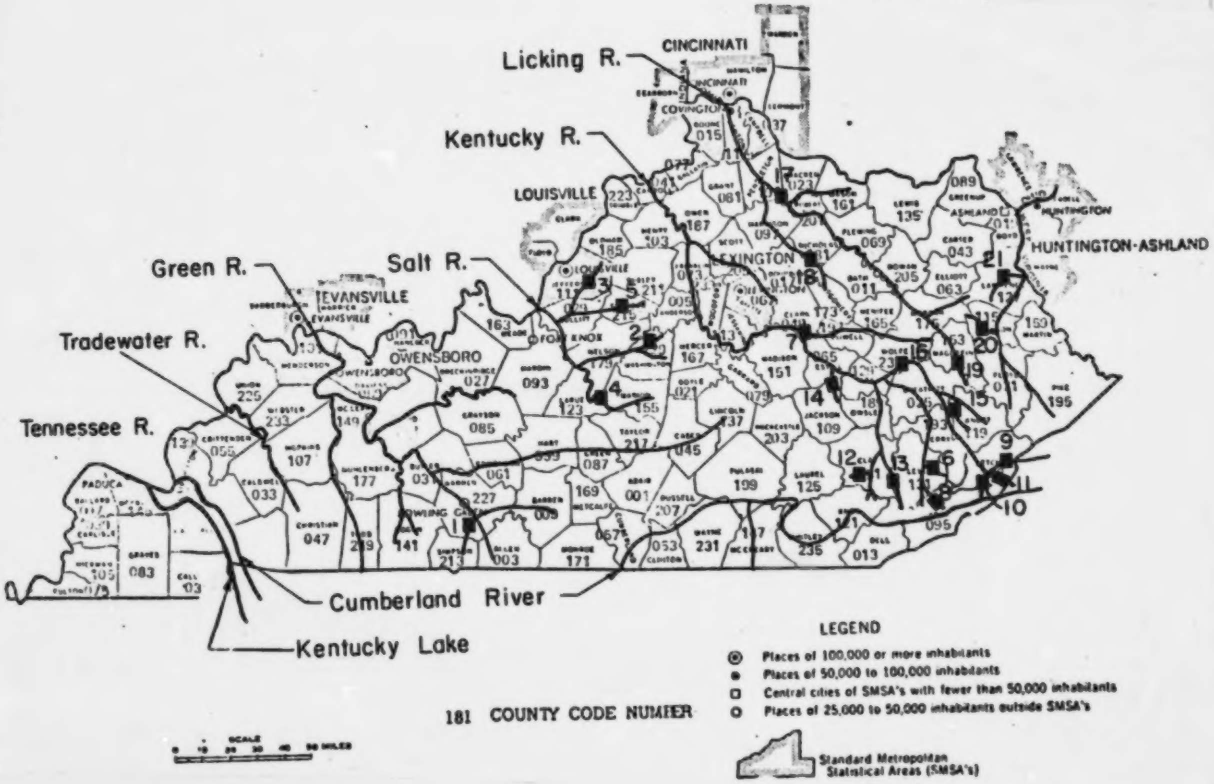
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HUNTINGTON
ASHLAND
Tradewater R.
Tennessee R.
PADUCAH
BOWLING GREEN
Cumberland River
Kentucky Lake
LEGEND
⦿ Places of 100,000 or more inhabitants
● Places of 50,000 to 100,000 inhabitants
☐ Central cities of SMSA's with fewer than 50,000 inhabitants
○ Places of 25,000 to 50,000 inhabitants outside SMSA's
Standard Metropolitan Statistical Areas (SMSA's)
181 COUNTY CODE NUMBER
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FIGURE 2.9. SELECTED RESERVOIR SITES IN KENTUCKY

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TABLE 2.13 SELECTED POTENTIAL RESERVOIRS IN OHIO[39]

Location No.[40]	Reservoir	Drainage Area (sq. mi.)	Total Storage (ac-ft)
1	Boggs Fork	15	5,000
2	Conser Run	15	5,100
3	Frazeysburg	62	62,000
4	Hugle Run	9	8,200
5	Middle Branch	27	9,300
6	Millersburg	381	77,000
7	Ogg	12	8,500
8	Skull Fork	46	15,000
9	Utica	114	82,000
10	Valley Run	25	15,100
11	Alum Creek[41]	123	124,000
12	Bellepoint	736	88,200
13	Mill Creek	181	92,500
14	Roundhead	34	11,900
15	Upper Darby	239	32,500
16	Cowan Creek	51	14,000
17	Morrow	685	244,000
18	Washington Mills	308	61,000
19	Todd Fork	245	95,000
20	Dry Fork	45	37,000

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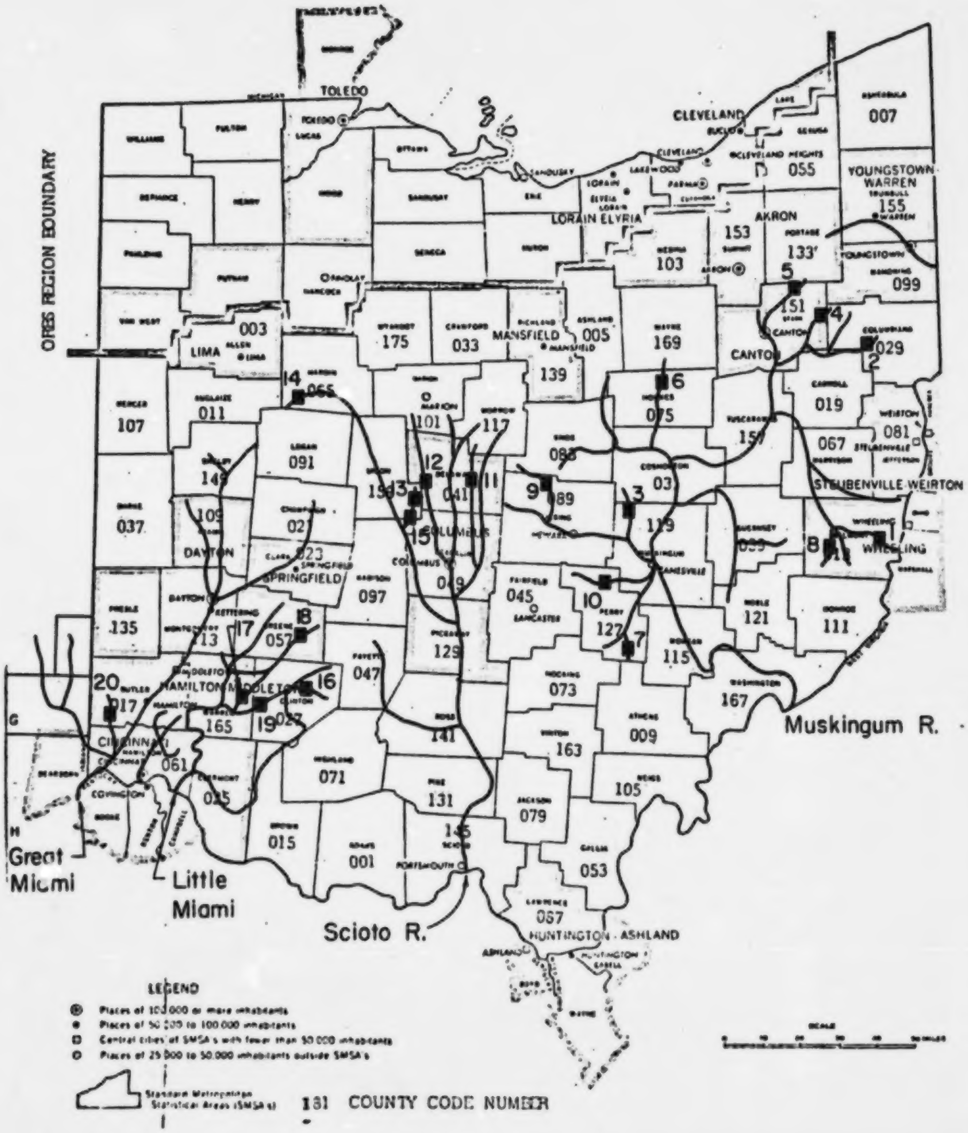
[39] Reference 2.
[40] Locations are indicated by number in Fig. 2.10.
[41] Under construction, Reference 13.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HAMILTON MIDDLETOWN
CINCINNATI
STEUBENVILLE-WEIRTON
WHEELING
HUNTINGTON - ASHLAND
Great Miami
Little Miami
Scioto R.
Muskingum R.
LEGEND
Places of 100 000 or more inhabitants
Places of 50 000 to 100 000 inhabitants
Central cities of SMSA's with fewer than 50 000 inhabitants
Places of 25 000 to 50 000 inhabitants outside SMSA's
Standard Metropolitan Statistical Areas (SMSA's)
131 COUNTY CODE NUMBER

FIGURE 2.10. SELECTED RESERVOIR SITES IN OHIO

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TABLE 2.14 SELECTED POTENTIAL RESERVOIRS IN PENNSYLVANIA[42]

Location No.[43]	Reservoir	Drainage Area (sq. mi.)	Total storage (ac-ft)
1	Laurel Hill Creek	115	62,000
2	Clear Shade Creek	29	16,000
3	Mill Creek	833	856,000
4	North Branch	28	22,000
5	Shanksville	32	25,000
6	Sugar Creek	98	31,000
7	Redbank Creek	460	142,000

[42] From Reference 2.

[43] Locations are indicated by number in Fig. 2.11.

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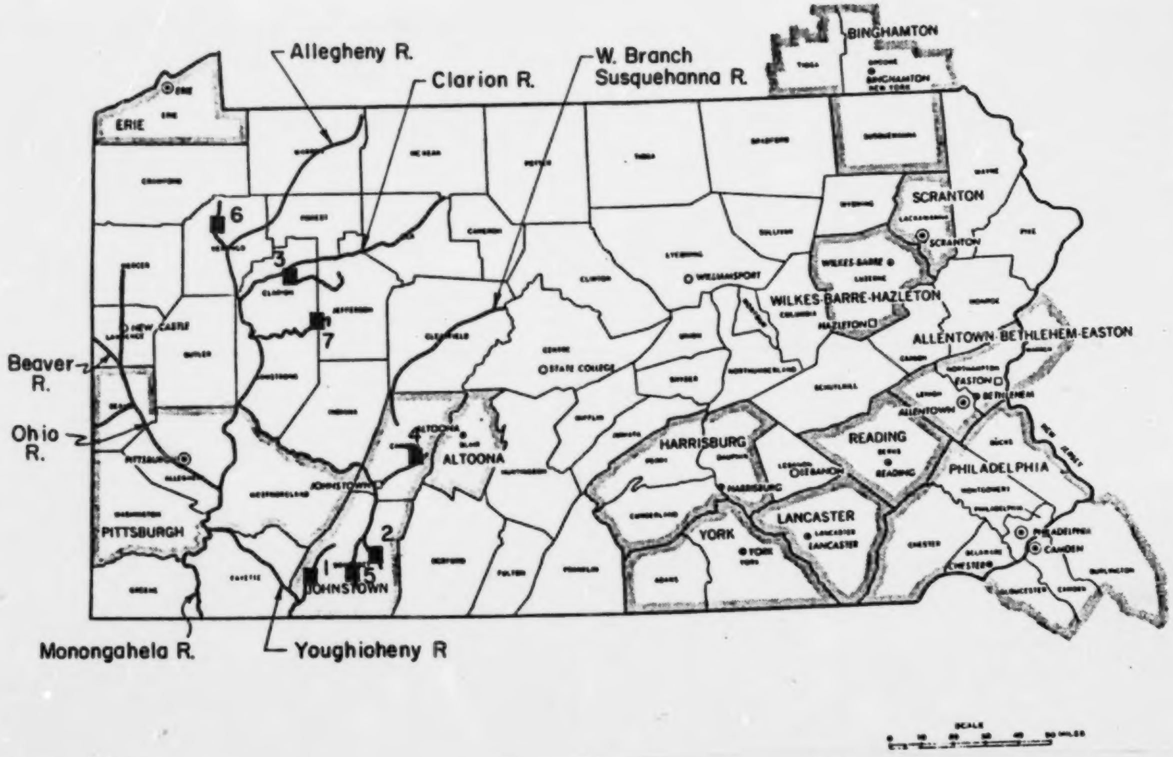
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FIGURE 2.11. SELECTED RESERVOIR SITES IN PENNSYLVANIA

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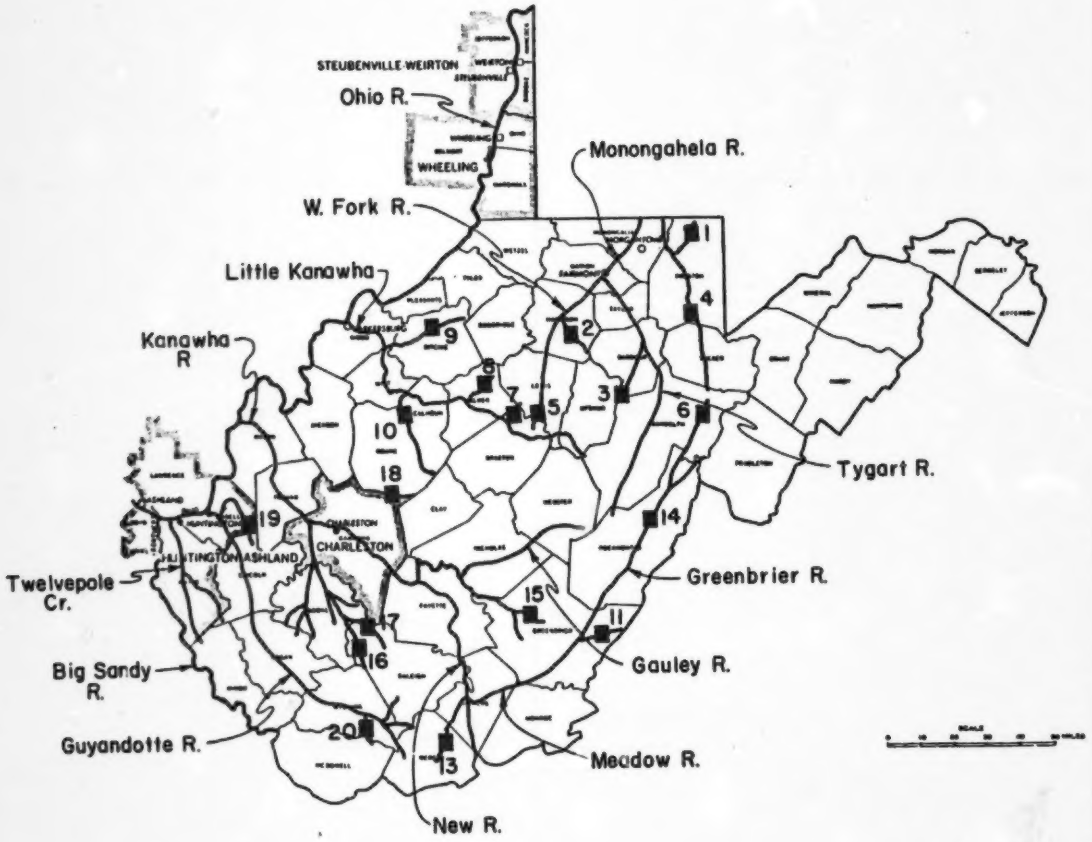
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CHARLESTON
HUNTINGTON-ASHLAND
Twelvepole Cr.
Greenbrier R.
Big Sandy R.
Gauley R.
Guyandotte R.
Meadow R.
New R.

FIGURE 2.12. SELECTED RESERVOIR SITES IN WEST VIRGINIA

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TABLE 2.15 SELECTED POTENTIAL RESERVOIRS IN WEST VIRGINIA[44]

Location No.[45]	Reservoir	Drainage Area (sq. mi.)	Total Storage (ac-ft)
1	Big Sandy Creek	97	87,000
2	Elk Creek	84	129,000
3	Middle Fork River	137	228,000
4	Rowlesburg	936	831,700
5	Stonewall Jackson	102	75,200
6	Wymer	44	115,000
7	Burnsville	166	66,000
8	Leading Creek	146	62,400
9	N. Fork Hughes River	90	30,000
10	West Fork	238	85,100
11	Anthony Lake	143	301,000
12	Big Reed Island Creek	259	391,100
13	Bluestone River	232	320,000
14	Greenbrier	350	561,000
15	Meadow River	322	140,000
16	Marsh Fork	44	100,000
17	Clear Fork	39	100,000
18	Big Sandy Creek	94	53,300
19	Mud River	270	90,300
20	Pinnacle Creek	56	25,300

[44] From Reference 2.

[45] Locations are indicated by number in Fig. 2.12.

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

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EPA-287 (Cin.)
(4-76)

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EPA-287 (Cin.)
(4-76)

3. WATER USE CALCULATIONS AND PROJECTIONS

3.1 INTRODUCTION

This chapter presents water use projections for the ORBES portions of Illinois, Indiana, Kentucky, Ohio, Pennsylvania, and West Virginia. Projections of municipal, self-supplied industrial, and irrigation water use are described. Cooling water requirements for individual power plants are discussed in Chapter 4, and regional water consumption for power plants is discussed in Chapter 6. In all cases the dual issues of water withdrawals and water consumption are investigated here under the more general heading of use.

In general the projection methodologies presented here draw heavily upon work begun in Phase I and described in the ORBES Special Study Report, "Issues Related to Water Allocation in the Lower Ohio River Basin" (1). The material presented here, however, includes significant revisions and additions to the earlier work.

Projections of municipal and self-supplied industrial use are described first. These projections were actually made on a county by county basis, although only the totals for the ORBES portions of the above states are presented here. The projections of water use for irrigation have generally been made on a state, rather than county, basis.

In-stream water uses—such as navigation, recreation and wildlife conservation—are not explicitly discussed in this chapter. For a brief discussion of water use for navigation in the region, the reader is referred to the Phase I report (1). While in-stream uses are not expressly examined here, they would clearly be affected by the impacts on water availability and water quality which are specifically addressed in this report as well as in references 1 and 2.

It should also be noted that it is difficult to measure and compile figures on even present water use. It is even more difficult to reliably project water use, since such projections depend on future populations, lifestyles, incomes, relative prices and technological developments, as well as on reliable base-year water use data. Therefore, the figures presented here should be interpreted cautiously; they are more likely to represent orders of magnitude than specific values. This is especially true, of course, for the longer range projections.

Of the figures presented in this chapter, the projections of water withdrawals and consumption for municipal and industrial uses are probably the more reliable. The projections of water use for irrigation are less certain, because in some areas growth of irrigation may occur by the year 2000 which would not be readily inferred from past trends.

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EPA-287 (Cin.)
(4-76)

In all cases the reader should note that the projections for both withdrawals and consumption are based on present technologies and life-styles. These use projections should not be considered identical to "requirements" because of the major potential for conservation.

3.2 MUNICIPAL WATER USE PROJECTIONS

3.2.1 Withdrawals

Water withdrawals for municipal supplies have been projected on a county basis for the portions of all states within the ORBES region. Basically, withdrawals have been projected to increase in proportion to population growth, although the methodology varies slightly from state to state depending on the type of data which were available. While only state totals for the ORBES portions of the six Phase II states are presented in this chapter, the county projections were used to analyze the local impacts of water consumption in the analyses presented in Chapters 5 and 6.

For all states in the Phase II region at least one set of municipal withdrawal projections has been made. This common set of projections has been based on data from water resource basin studies (3, 4, and 5). An additional set of projections has been made for Kentucky, Ohio, and Pennsylvania, based on data recently compiled in those states (6, 7, and 8). Similarly, additional projections, or modifications of the existing figures, may be made for Indiana, based on data which have just been received from this state (24). Because the states' data have been compiled more recently than the basin study data, the second set of projections for Kentucky, Ohio, and Pennsylvania is probably more accurate than the projections which were based on the basin study data. Therefore, this second set of figures is being used in our work, where available. Encouragingly, however, the two sets of projections for these three states are generally similar. In this chapter only the more recent set of projections is presented for states where two sets exist. This set corresponds to the figures which were actually used in preparing the consumption ratio analysis presented in Chapter 5.

The withdrawal projections have been made using county population projections supplied by the ORBES Phase I group (9), where these projections were available. These figures were available for Illinois, Indiana, and Kentucky counties. For Ohio, Pennsylvania, and West Virginia, county population projections were made here by disaggregating recent population projections for multi-county regions from the OBERS Projections (10). The county projections are based on exactly the same procedure used to project Ohio's population in Phase 1, which is mentioned in the Phase I report (1). The general conclusion of the above discussions is that the county population projections made in this fashion are quite reasonable, especially in view of the other, greater uncertainties associated with making water use projections.

3.2.1.1 Projection method I—per capita use

The set of projections which is common to the six states was made based on a per capita use figure for each county in the ORBES region. This set is the basis for the figures presented in Table 3.1 for Illinois, Indiana, and

EPA-287 (Cin.)
(4-76)

TABLE 3.1 MUNICIPAL WATER WITHDRAWAL PROJECTIONS IN MILLION GALLONS PER DAY[1]

State [2]	1970	1975	1985	2000
Illinois	290	300	310	350
Indiana	470	500	510	590
Kentucky	390	410	450	530
Ohio	820	860	940	1040
Pennsylvania	400	420	460	530
West Virginia	150	160	160	160
Total	2500	2600	2800	3200

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[1] 1 million gallons per day = 1.55 cubic feet per second.

[2] ORBES portion of states only.

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AND ILLUSTRATIONS

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

West Virginia. The per capita use figures in gallons per capita daily (gpcd), were found for most counties in the Ohio River Basin Comprehensive Survey (ORBCS) (3). For a number of Illinois counties and Jasper county Indiana, the per capita figures were taken from the Upper Mississippi River Comprehensive Basin Study (UMRCBS) (4), and for five counties in northern Indiana, and nine counties in northern Ohio, approximate figures were derived from the Great Lakes Basin Framework Study (GLBFS) (5). In the few cases where no county per capita municipal use figures were available, approximate figures were assumed, based on use rates in neighboring counties. Where a county is located in two river basins or subbasins, the per capita figure is a weighted average based on the amount of population served by municipal systems in the two regions.

The per capita municipal use figure was then multiplied by the projected population for each county in the ORBES region to produce water use projections in million gallons daily (mgd). This methodology implicitly assumes that all population of a county uses water at the same rate as the population served by municipal supplies, and that the per capita water use rate will remain constant over the coming decades.

In reality, the entire population of a county does not necessarily use water at the same rate as the municipally supplied population. In addition to life-style differences between municipal and rural residents, the per capita municipal use figure reflects municipal service of some industrial, commercial, and civic users (e.g., fire supply, pools, and parks). Municipal systems may also have significant leakage.

Furthermore, although for this set of projections each county's per capita use figure has been kept constant at the 1960 level reported by the major references (3, 4, and 5), there are potential problems with this approach. First, in a few cases the basin study figures are excessively high to be considered a reasonable county-wide figure. A few per capita figures, for example, are above 200 gpcd. Another problem is that per capita domestic water use may be growing somewhat. The recent study of the Great Lakes Basin (5) (an area which resembles the ORBES region) suggests that per capita use may be increasing to 108 gpcd at an annual rate of 1% and thereafter at an annual rate of .25% to the level of 130 gpcd. While this growth factor could have been incorporated into the projections presented here, it was decided to leave per capita use constant through the year 2000. Leaving the rate constant helps compensate for the inclusion of non-municipally supplied population in the municipal use projections, and compensates at the state level for the few very high county use figures discussed immediately above. Finally, possible changes in water use due to income and price changes are not considered explicitly in these projections.

In spite of these factors, however, the methodology used here can be justified for a number of reasons, as follow:

1. If the assumption of county-wide use at the municipal rate implies a slightly higher level of withdrawals than might be expected, this result is acceptable for cautious environmental planning.

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

2. Although municipal and rural withdrawals are generally considered to be different, the consumption from these two uses is quite close on a per capita basis. Murray and Reeves (11) report for the U.S., for example, that the average per capita withdrawal rates for municipal and rural residents are 168 and 66 gpcd, respectively. These authors also report that in the U.S. in 1975 the average municipal consumption was 23% of withdrawals, while for rural domestic use the figure was 50%. These percentages imply consumption of 39 and 33 gpcd for municipal and rural users, respectively. The rural figure in the ORBES region would be even somewhat higher if one considers that the consumption rate is 95% for withdrawals used for livestock.

3. One important consideration for this study is incremental demand, i.e., the change in demand from one period to the next. In this context the technique used here is very similar to that of the GLBFS (5). Although the authors of the GLBFS comprehensively investigated rural water use, for planning purposes they assumed that all new population would use municipal systems.

4. Although the per capita use of municipally supplied water has been growing, this growth has been fairly slow. Per capita municipal use in the U.S. has grown from roughly 145 gpcd in 1950 (12), to 168 gpcd in 1975 (11), an increase of less than 16% in 25 years. In the past what has been relatively more important was the increase in population served by systems; this population has grown by roughly 80% in the U.S. over the past 25 years (11).

5. Based on a preliminary econometric study, the effect of income and price on per capita municipal use was found to be small. Furthermore, if real incomes rise with increasing productivity and water prices rise slightly (e.g., due to scarcity), as a first approximation it is not unreasonable to assume the two effects will cancel out.

In short, because of a number of uncertainties the projection method used here appears to be reasonably reliable. At the same time this method is relatively straightforward, and thus the projections produced can be interpreted fairly easily.

3.2.1.2 Projection method II—municipal pumpage

The water use projections presented for Kentucky, Ohio, and Pennsylvania in Table 3.1 are based on data supplied by the states rather than data from the basin studies. Projections for these states are actually the products of three slightly different methods.

Kentucky. Projections for Kentucky are based on maximum permitted withdrawals for any given month. Individual permit data for water withdrawals were received from the computerized files of the state's Division of Water Resources, Department for Natural Resources and Environmental Protection (6), and were aggregated to the county level here. The projections made here are based on ratios of county population in the years 1970, 1985, and 2000 to the county population in 1975. The ratios of population growth were calculated

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EPA-287 (Cin.)
(4-76)

from population projections supplied by ORBES in Phase I (9). The 1976 permit data are considered to approximate 1975 water use.

Note that the figure for permitted withdrawal for the maximum month is presented. It can be expected that this figure is above the average daily figure for any recent year. It is probably for this reason the projected totals of state municipal use are roughly 25% greater than the projections implied by the first set of projections. Maximum use does frequently occur in the hot summer months, however, which is when low-flows are expected, and it is the low-flow periods which are investigated in the consumption ratio analysis (see Chapter 5 and 6). Additionally, the permit data indicate that in practice the present permitted withdrawals have frequently been exceeded over the past ten years. Therefore, use of the maximum permitted withdrawal figure seems reasonable.

It should also be noted that the more urbanized population served by municipal supplies may in fact grow faster than the total county population, which in Kentucky's case includes a fair percentage of rural population which is not served by municipal systems. This relative urbanization would tend to counteract the "over-projection" implied by using peak permit data.

Ohio. The second set of Ohio county municipal use projections was based on 1975 public supply pumpage data received from the USGS in Columbus (7). Those data indicate ground and surface water withdrawals by county in mgd. The ground and surface water use were aggregated here and then projected to increase (or decrease) in proportion to the ratios of county population in 1970, 1985, 2000, and 2020 to population in 1975. (Only projections through 2000 are shown in this report.) As in the case of Kentucky, it was assumed that municipal supply could be projected using the ratios of county population projections which are not identical to projections of the actual population served by municipal systems. This assumption implies that the municipally supplied population will increase at the same rate as the entire county population.

Note also that domestic self-supplied water use is not included in the table of municipal use, although the USGS did provide calculations of such use by county (7). Their estimated total for the ORBES portion of the state for rural domestic self-supplied water use was 116 mgd in 1975.

A comparison of the two sets of Ohio municipal use projections indicates that the two are fairly similar. The state totals of municipal use are within 10% of each other for each year, from 1970 through 2020.

Pennsylvania. The second set of water use projections for Pennsylvania draws heavily upon data and projections supplied by the state's Department of Environmental Resources (8). This agency provided water use data for 1970 and projections for 1980 and 1990. The figures were compiled by watersheds and river subbasins by the state. Note that for Pennsylvania the second set of projections is not literally based on "county" projections, but rather on watershed regions which are of similar size. There was no need to get actual county figures in this case, because the subbasin boundaries correspond well to the river reach framework of the consumption ratio analysis (see Chapters

EPA-287 (Cin.)
(4-76)

5 and 6). Furthermore, disaggregations and reassembly into county data would have involved many approximations and would have meant losing much of the quality of the data which were provided. When a watershed extended outside of ORBES boundaries, an adjustment was made to water use in it based on the percentage of the watershed's land mass within the ORBES region and also taking into account the location of municipalities within it.

The 1975 figures for Pennsylvania presented in Table 3.1 are linear interpolations of the 1970 and 1980 figures; the 1985 figures likewise represent interpolations of 1980 and 1990 estimates. The projections for 2000 are based on an approximating assumption (made here) that the increase in water use between 1990 and 2000 (in mgd) will be exactly the same as between 1980 and 1990. While self-supplied domestic use is projected by the state, these figures have not been included in the table of municipal use. For 1970, this use is reported to be about 36 mgd for the ORBES portion of Pennsylvania.

Comparison of the two sets of municipal use projections for Pennsylvania shows the two to be similar. The two sets of state totals for municipal use are within 10% of each other for 1970, 1975, and 1985 and are within 20% for 2000.

3.2.2 Consumption

Table 3.2 presents projections of municipal water consumption. These figures were calculated by assuming that consumption represents 20% of municipal withdrawals. Average consumption of municipally supplied water in the U.S. was estimated to be 23% of withdrawals in 1975 by Murray and Reeves (11) and 22% in 1970 (13). In the GLBFS consumption of domestic and commercial municipal supply is estimated to be about 10% (5, p. 4). In calculating municipal consumption the Pennsylvania data sheets (8) also use the figure of 10%.

As noted earlier, Murray and Reeves (11) suggest that in 1975 rural water used for domestic and livestock supply was subject to consumption rates of 50% and 95%, respectively. These percentages were 65 and 90% in 1970 (13).

Because this special study has generally stressed consumption related issues, it should be emphasized that the choice of a consumption figure is very important. Clearly, the difference between the 10% and 20% consumption rates of municipal withdrawals is significant. The range of consumption estimates impled by this choice (basically a 100% difference) probably far overshadows errors associated with the municipal withdrawal projections. The 20% rate used in this study is somewhat "cautious" as far as planning is concerned.

3.3 SELF-SUPPLIED INDUSTRIAL WATER USE PROJECTIONS

Self-supplied industrial water withdrawals may account for as much as 90% of all industrial withdrawals (5, p. v.); the remaining percentage is municipally supplied. In this report, and in all studies cited, discussions of industrial withdrawals exclude the power generation industry.

TABLE 3.2 MUNICIPAL WATER CONSUMPTION PROJECTIONS IN MILLION GALLONS PER DAY[1]

State[2]	1970	1975	1985	2000
Illinois	59	59	61	70
Indiana	93	99	100	120
Kentucky	77	82	90	110
Ohio	160	170	190	210
Pennsylvania	80	83	91	110
West Virginia	31	31	32	32
Total	500	520	560	640

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[1] Assumes consumption is 20% of projected withdrawals.

[2] ORBES portion of states only.

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PAGE NUMBER

EPA-287 (Cin.)
(4-76)

In projecting industrial water use it is important to distinguish between water withdrawals and water consumption. Because of water pollution discharge regulations and limits of readily available water in some locales, over the past years recycling of industrial water within plants has become increasingly important. Additionally, introduction of cooling towers into some industrial (non-power) plants which use water for cooling also acts to lower the amount of water which industrial users must withdraw.

Therefore, there is reason to believe that even with the large projected increases in manufacturing output for the ORBES region (see e.g., reference (10)), industrial water withdrawals in the year 2000 may be roughly the same as in the early 1970s. This trend is suggested for the similar, neighboring Great Lakes region by the authors of the GLBFS (5, p. 1). The trend of fairly constant withdrawals accompanying increased industrial output has also been observed by Schnepper, *et al.* (14) in a study of industrial water use in Illinois.

The authors of the GLBFS used "value added in manufacturing" as their measure of industrial growth. They projected a 600% increase in value added from 1970 to 2020 in the Great Lakes region. They assert that industrial water withdrawals cannot be projected to increase at such a high rate, though consumption may increase in these magnitudes. Furthermore, they even suggest industrial water withdrawals may decline during the coming years. After a period of decline in withdrawals while industrial plants are improving their efficiency levels, it is expected that withdrawals will begin to increase because of industrial growth. Thus, withdrawals in 2000 may be generally equal—depending on the subarea of the Great Lakes basin—to those in the early 1970s. By 2020 withdrawals are projected to be about 10% more than 1970. This picture would be complicated, of course, by changes in wastewater treatment requirements and by additional reuse caused by local water shortages. For this study, it is believed that rather than planning on a decrease in withdrawals, the more cautious planning approach would be to assume a constant level of withdrawals from the early 1970s through 2000.

3.3.1 Withdrawals

Figures for self-supplied industrial withdrawals in the early 1970s are presented in Table 3.3 for the ORBES portions of the six states in the Phase II region. As in the case of the municipal projections, the industrial figures are based on aggregated county data. The data sources for these figures are as follows:

Illinois. Survey data received from the computerized files of the State Water Survey (15) were the basis for the study by Schnepper, *et al*, (14). For some counties these data were supplemented here by data from the ORBCS (3) and UMRCBS (4). In some cases the basin study data were projected from the 1960s assuming growth of water withdrawals proportionate to growth of manufacturing earnings. Estimates and projections of manufacturing earnings were obtained from the OBERS Projections (10). The growth rates of these earnings figures for multi-county regions (SMSA and non-SMSA economic areas) were then applied to the industrial water withdrawals for the individual counties within each economic area.

EPA-287 (Cin.)
(4-76)

TABLE 3.3 BASE YEAR SELF-SUPPLIED INDUSTRIAL WITHDRAWALS IN MILLION GALLONS PER DAY

State[1]	1970	1975
Illinois	590	--
Indiana	280	--
Kentucky	--	450
Ohio	--	1700
Pennsylvania	3000	--
West Virginia	1600	--

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[1] ORBES portion of states only.

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EPA-287 (Cin.)
(4-76)

Indiana. The 1970 figures are based upon data from the river basin studies (3, 4) which were projected from the 1960s using manufacturing earnings as described for Illinois above. For the five northern ORBES counties in the Great Lakes basin, these figures were augmented by disaggregating data from the GLBFS (5) on the basis of value added in the five counties.

Kentucky. Estimates for 1975 withdrawals are based on industrial water withdrawal permits (6) for the maximum month of the year 1976.

Ohio. Estimates for withdrawals are based on estimated 1975 use figures supplied by the USGS (7).

Pennsylvania. Data provided by the state (8) based on an in-depth survey of water use and tabulated by watershed and water resource subbasin.

West Virginia. The 1970 figures are based on data from the ORBCS (3), which were projected here from the early 1960s using manufacturing earnings.

While it is difficult to project industrial withdrawals, again, present trends suggest that it may be reasonable to assume that on a regional level withdrawals will remain essentially constant from the early 1970s through 2000.

As in the tables of municipal use, where two data sets exist only the set judged to be more reliable is presented in this chapter. For Illinois, Kentucky, Ohio, and Pennsylvania, additional base-year data sets exist because the river basin studies (3, 4) were originally used as data sources for all states in the ORBES Phase II region.

The data recently supplied by the individual states were judged to be superior, however, to the basin study data for two reasons. First, the state data were compiled more recently than the basin study data, some of which are about fifteen years old. Second, the state data are based on either permit data or a fairly thorough survey of actual water use by county. The river basin study data are generally based on water use coefficients for different industries. These coefficients are used to assign amounts of industrial water withdrawals to counties, based on the counties' employment or dollar value of output in different industrial classifications.

3.3.2 Consumption

Projected estimates of industrial water consumption are presented in Table 3.4. This special study has generally concentrated on examining consumption-related impacts because water which is consumed—e.g., through evaporation or incorporation into products—is not available for reuse. Therefore, the projections of self-supplied industrial water consumption are of greater importance to this investigation than exact projections of withdrawals.

Industrial consumption has been projected, however, using the base-year withdrawal data. The procedure entails artifically projecting county-wide industrial withdrawals to continue to increase proportionately with projected manufacturing earnings from 1970 through 2000. The county earning projections were calculated by disaggregating multi-county earnings projections calculated

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 3.4 PROJECTED SELF-SUPPLIED INDUSTRIAL WATER CONSUMPTION IN MILLION GALLONS PER DAY

State[1]	1970	1975	1985	2000
Illinois	59	71	96	150
Indiana	28	35	49	80
Kentucky	36	45	65	110
Ohio	140	170	220	320
Pennsylvania	300	320	340	370
West Virginia	160	180	230	310
Total	720	820	1000	1300

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[1] ORBES portion of states only.

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EPA-287 (Cin.)
(4-76)

by OBERS (10). Consumption is then estimated by taking a constant percentage—e.g., 10% in Table 3.4—of the projections of withdrawals made in the above manner. The 10% figure is based on the average consumption of self-supplied industrial water in the U.S. in 1970, as reported by Murray and Reeves, (13).

Note that as explained in the above sections, withdrawals are actually expected to remain essentially constant from 1970 through the year 2000. Withdrawals are projected using manufacturing earnings in this instance only to provide a means of projecting consumption. The essential result of this procedure is that while withdrawals are expected to remain approximately *constant*, *consumption* is projected here to increase in proportion to manufacturing earnings.

There are two potential shortcomings with this procedure. First, the manufacturing earnings were not broken down into different industrial classifications here to account for different rates of growth in different industrial sectors. Second, different rates of water consumption by the different industries were not explicitly examined.

Despite the above shortcomings, there are a number of reasons that the procedure used here is appropriate. First, in many cases it was not possible to obtain data on industrial withdrawals by county according to the industrial classification of the users. In addition even users within a classification can consume water at very different rates, depending on the intended use of the withdrawn water.

Another question is whether earnings growth is the proper means of projecting consumption. Although this measure is imperfect, earnings do provide a good measure of physical output. Output in turn reflects the incorporation of water into products as well as the evaporation of water because of its use in cooling. In fact, if recycling cooling water raises the water's temperature above that of water which would be withdrawn in a once-through cooling system, then one would expect to see an even higher rate of evaporative consumption per dollar output in systems which recycle water. The only exception to this observation would be due to the adoption of dry cooling techniques, which are considerably more expensive—and less common—than the cooling technologies which are widely used at present.

Finally, it should be noted that the projection of consumption to increase in proportion to manufacturing earnings is essentially consistent with the projections of the *GLBFS* (5, pp. vi, 18, and 50). For the Great Lakes region that source projected a six-fold increase in earnings from 1970 to 2020 accompanied by a near seven-fold increase in industrial consumption.

As in the case of the municipal consumption calculations, the choice of the percentage of withdrawals used to calculate industrial consumption may overshadow other shortcomings of the projection methodology. Although a rate of 10% was used to derive the figures in Table 3.4, there are other rates which could be considered. As was noted earlier. the 10% rate was cited by Murray and Reeves as the average U.S. rate in 1970 (13). In 1975 these same investigators found the rate to be 11% (11). The *1972 Census of Manufacturers* (16), however, suggested an average rate of 6% in the U.S. in 1973. This figure is consistent with the consumption figures generated by the Pennsylvania Department of Environmental Resources (8), which suggested roughly 6.3% consumption in the ORBES portion of that state in 1970. According to water basin figures in the 1972 Census of Manufacturers (16, p. SR4-27), the Ohio River Water Use Region in 1973 had consumption levels on only about 4%, while the Upper Mississippi and Great Lakes regions had rates of about 8 and 5%, respectively. Finally, Schnepper *et al.* (14) cited an 8% national average from the 1967 Census of Manufacturers in their study of industrial water use in Illinois in 1970. The 10% rate has been used here because it is our best prognosis of the actual rate, and also because it is on the cautious side of the rates presented.

3.4 TOTAL (MUNICIPAL AND SELF-SUPPLIED INDUSTRIAL) WATER USE

Projected total consumption due to municipal and self-supplied industrial water use is shown in Table 3.5. These figures are the sums of figures from Tables 3.2 and 3.4 rounded off to two significant digits. These figures represent the consumption estimates which this special study views as most likely. These estimates were calculated assuming municipal consumption would be 20% of projected withdrawals, and that industrial consumption would be 10% of the withdrawals which were "projected" using manufacturing earnings. Again, as discussed in section 3.3, while self-supplied industrial withdrawals are actually expected to remain relatively constant through the year 2000 due to recycling, here the projection methodology used earnings to "project" increased industrial water withdrawals, in order to project expected industrial consumption indirectly.

Figures showing a reasonable range of total municipal and industrial water consumption for the Phase II region are presented in Table 3.6. These figures were calculated using percentages discussed in the sections on municipal and industrial consumption (3.2.2 and 3.3.2) in order to generate reasonable "low" and "high" consumption estimates. The "low" estimate is based on the application of a 15% consumption factor to municipal withdrawals and a 6% consumption factor to "projected" industrial withdrawals. The "high" estimate is based on the assumption of municipal and industrial consumption factors of 23% and 11%, respectively.

These "low" and "high" estimates should be interpreted as showing a likely range for consumption in the future. The wide range of figures for each date in Table 3.6 demonstrates that there is a fairly wide band of uncertainty attached to the figures presented in Tables 3.2, 3.4, and 3.5. Furthermore, the ranges of the figures presented in Table 3.6 do not represent strict bounds; it is entirely possible that either the "low" or the "high" estimates could be exceeded, due to changes in technologies or lifestyles, for example.

3.5 OTHER WATER USE INVESTIGATIONS

As Table 3.6 illustrates, by varying the municipal and industrial consumption factors within a reasonable range a wide band of potential consumption figures is suggested. The range of "high"and "low" estimates presented in this table was derived, however, solely by varying the consumption factors.

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 3.5 PROJECTED TOTAL[1] WATER CONSUMPTION IN MILLION GALLONS PER DAY

State[2]	1970	1975	1985	2000
Illinois	120	130	160	220
Indiana	120	130	150	200
Kentucky	110	130	160	220
Ohio	300	340	410	530
Pennsylvania	380	400	430	480
West Virginia	190	210	260	340
Total	1200	1300	1600	1900

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[1] Municipal and self-supplied industrial.

[2] ORBES portion of states only.

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 3.6 A RANGE OF PROJECTED TOTAL[1] WATER CONSUMPTION ESTIMATES FOR THE ORBES PHASE II REGION IN MILLION GALLONS PER DAY

	1970	1975	1985	2000
"Low" Estimate[2]	810	880	1000	1200
"Best" Estimate[3]	1200	1300	1600	1900
"High" Estimate[4]	1400	1500	1700	2100

---

[1] Municipal and self-supplied industrial.

[2] Assumes a municipal consumption factor of 15% and an industrial consumption factor of 6%.

[3] Assumes a municipal consumption factor of 20% and an industrial consumption factor of 10%.

[4] Assumes a municipal consumption factor of 23% and an industrial consumption factor of 11%.

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

Not presented is the even wider range which would result from using either different projection methods or different estimates of base-year water use.

The presentation of water use data to only two significant digits in this chapter and the wide range of figures implied by parameterization of the municipal and industrial consumption factors, should ideally result in general coverage of the likely range of future water use. Furthermore, water use by power generation is generally of a large enough magnitude to render small inaccuracies in municipal and industrial water use estimates inconsequential to the analysis presented in this report.

Parties with special interests in water use figures, however, should note that a number of sources exist which present water use figures which could supplement those given in this chapter. Basin studies (3, 4, 5, 16), for example, present water withdrawal projections for areas within the Phase II region. However, in the case of the ORBCS (3)—which covers most of the region—these projections are more than ten years old. Fairly recently the Ohio River Basin Commission (18) has compiled accounting sheets (including projections in many cases) for a number of counties along the Ohio River main stem.

Projections or base-year data are also available by county for some states in sources not previously cited. Projections of water use in Illinois can be found in references 19, 20, and 21. A number of Kentucky counties near the Ohio River are considered in projections described in references 22. Additional information on water use in Kentucky can be found in reference 23. For Ohio, Murray and Reeves (11) cite a work by Rudnick, though this study group has not reviewed that piece.

Water use data for Indiana have recently been compiled there by a study commission (24), and preliminary draft copies have become available. These preliminary data include projections of municipal and industrial use. Unfortunately, the projections are reported by economic regions which are aggregations of several counties, and not by individual county. These projections, however, do separately examine withdrawals and consumption for municipal and industrial uses as well as for rural, irrigation, and energy water uses. The municipal and industrial projections developed here have been compared for the ORBES portion of Indiana with these recent state projections and there is reasonable agreement.

Finally, the issue of peak versus average water use is not generally dealt with in these projections. The municipal and industrial figures presented in this report generally represent average withdrawal and consumption values. The only exception is for Kentucky, as mentioned in the text (section 3.2.1.2), where the figures represent the maximum permitted monthly withdrawal. According to the GLBFS (5, p. 4) peak daily usage may be considered to be roughly 50% greater than average daily use. This figure is consistent with data reported in reference (21), for the state of Illinois. Average daily demand during peak months is estimated in the GLBFS (p.4) to be 20% greater than average daily demand taken over the year. Although it might be reasonable to assume that peak usage might occur during hot summer months—when low-flows are most likely in many areas—except for the case of Kentucky no explicit recognition has been made of this observation by this investigation.

3.6 IRRIGATION

Because of the many questions surrounding its development in the ORBES region and the difficulty of making confident projections, irrigation has not been considered in the above discussion of "total" water use, nor is it considered in the consumption analyses of Chapters 5 and 6. In lieu of presenting specific projections, this section is designed to give readers general understanding of the potential importance of future irrigation, key factors which would affect future developments, and finally a range of potential estimates of future practices.

At present the percentage of agricultural land in the ORBES region which is irrigated is one of the lowest in the nation (25). In fact, drainage of farm soils which often actually show a surplus of water has been an important problem in many parts of the region (19, 26).

Recently, however, the potential for supplemental irrigation in the region during droughts has been receiving increasing attention. Because irrigation is very highly consumptive of water, and because potentially vast increases of irrigated acreage have been suggested by some sources, examination of possible irrigation developments is of major importance to long-range water resources planning for the region.

Experts' views vary widely concerning the prospects for irrigation in the ORBES region. Projections of irrigation based on historical trends show continuing, yet moderate growth. Some agricultural experts have suggested, however, that the potential exists for major expansion of irrigation in the region (27, 28, 29). If the extreme projections hold, irrigated acreage in parts of the basin could increase by more than ten-fold by the year 2020, or even by 2000. In contrast some other investigators believe that much of projected—and even present—irrigation will not be economically profitable (30).

Although water withdrawals and consumption by irrigation may become very important in coming decades, of all the major uses of water, demands for irrigation are probably the most difficult to project. The following quote, from a thorough study of Illinois's water resources in the late 1960s may give one a feel for the "state of the art" of irrigation projections. The authors of Water for Illinois: A Plan for Action (19, p. 231) wrote:

> At this time, there does not appear to be a reasonable method for projecting the rate of growth of irrigation, or predicting when any rapid expansion might occur. The [U.S. Senate] Select Committee on Water Resources predicted an increase in irrigated acreage of Illinois of approximately 3 million acres, or 12 percent of the crop land, by the year 2000. This is 205 times the 1964 acreage. . .Since such growth likely would not be continuous, it is quite probable that much of this growth will occur within a span of a few years, when economic benefits, possibly related to a major corn-belt drought or national needs for food dependent on optimum yields, suddenly develop. However,

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

there is no scientific or economic basis for estimating when such an increase might occur.

Because of the difficulty of making irrigation projections, a following section will present a range of reasonable estimates for each state, rather than attempting to arrive at a single number for the year 2000. Note that even if the high end of estimates is not attained by that date, these high figures might reflect use at a later date, such as 2020, and therefore these figures are not irrelevant to resources planning over coming decades.

3.6.1 Factors Affecting Irrigation Projections

Projections of irrigation are affected by both agronomic and economic factors. Because agriculture is ultimately a business enterprise, it can be reasonably asserted that even technical agronomic factors become matters of degree and that economic factors eventually dominate irrigation decisions. For example, while the yield increases in some areas due to irrigation may be viewed as pure agronomic factors, economics then enters because the actual decision to increase yield requires an explicit calculation of benefits and costs. For expository purposes, however, the distinction between agronomic and economic factors is useful.

Among the most important of the agricultural factors is the soil type. Specifically, the ability of the soil to retain water, and the penetrability of the soil to plant roots are the two most critical aspects. In Illinois, for example, areas projected to be especially conducive to irrigation are characterized either by relatively fast-draining sandy or sand loam soils or by soils which have a hard clay pan beneath the surface (21). Similarly, in Indiana irrigation is projected to expand most in areas with soils which tend to be droughty, such as coarse or moderately coarse soils which overlie sand or gravel (28).

Other physical factors affecting the spread of irrigation are the land topography and water availability. In general, hilly areas would be expected to be less conducive to irrigation all other factors being equal, though recently there has been some irrigation growth on hilly terrain in West Virginia using traveling sprinklers (31). Drip irrigation systems could also be useful in hilly or mountainous terrain (32). Obviously the physical accessibility of water would also have a major affect on the spread of irrigation. In Illinois, Mason county, which dominates the state's irrigated acreage, is located above a major ground water aquifer. In Indiana the droughty soil areas also appear to be rich in ground water (28). In other parts of the ORBES region the accessible water may largely come from surface supplies; the specific state by state breakdown of irrigation water sources will be discussed below in the section on state projections.

Crop types would also affect the amount and timing of water use for irrigation. In Illinois and Indiana, and to a lesser extent West Virginia, the major thrust of projected irrigation is expected to be supplemental irrigation of corn crops. One important reason for irrigating corn is that the critical silk emergence stage which occurs in late July and August often coincides with

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

hot, dry spells. In Ohio and to a lesser extent Pennsylvania, growth is expected largely in the irrigation of horticultural crops such as vegetables, fruits, and nursery stock (26).

Because all the above factors are essentially matters of degree, the interplay of economic factors with agronomic ones will ultimately determine the extent of irrigation expansion. Economic factors, for example, reflect both the quantity and price of demand for crops, as well as the prices of inputs to crop production. Much of the difficulty of projecting irrigation demand, in fact, results from the near impossibility of projecting the relative prices of different inputs and crops far into the future.

Among the most important economic factors are the relative prices of such inputs as land, labor, fertilizer, energy and water. The present trend of increasing land prices in much of the region, for example, may encourage more intensive cultivation of land, and hence may increase demand for irrigation. Crop prices and accessibility to markets also play important roles in determining the extent of irrigation. Much of the acreage in Indiana which is expected to support irrigation is quite close to the large demand center of Chicago.

The changing structure of the agricultural sector may also affect development patterns. Agribusiness may have more funds to invest and may have a longer planning horizon than single family farmers. Successful irrigation in the ORBES region will also require sound management practices. These techniques are likely to become increasingly common with rising levels of agricultural education and agribusiness.

While trends of rising levels of land prices, crop prices, management expertise, and agribusiness indicate increased potential for irrigation, other factors may moderate or counteract them. Importantly, irrigation at present entails increased inputs of labor, fertilizer, energy, and water. Costs per unit output may in fact rise with irrigation, and prices of the increased inputs may rise as fast—or faster—than land or produce prices or yields. Another major factor affecting irrigation development is the federal crop reduction subsidies. Such subsidy to farmers to reduce their planted acreage would strongly affect the need for and the profitability of raising yields via irrigation. As the authors of reference 33 (p. 17) write, "It is difficult... to justify state support for developing irrigation water supply so long as extensive Federal subsidy is maintained to prevent over-production. Over two million acres of Illinois cropland were kept out of production by this subsidy in 1968." For these types of reasons not all experts are convinced that increased irrigation in the ORBES region—and other relatively humid regions—will be profitable or should be encouraged.

Other factors which would affect the spread of irrigation are the legal barriers affecting access to water. In Illinois, for example, the authors of Water for Illinois: A Plan for Action (19, p. 232) wrote, "The State's water laws, which are based on riparian doctrines, could limit widespread adoption of irrigation. New laws would be needed to mediate the controversies which would develop over water rights for irrigation." According to maps supplied by the U.S. Soil Conservation Service (34), all six states in the ORBES region

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

are covered by the riparian rights doctrine with respect to surface water supplies. According to these maps, Indiana, Ohio, and Pennsylvania also are covered by the riparian doctrines with respect to groundwater. Illinois, Kentucky, and West Virginia are classified as being covered by a doctrine of "reasonable use" for groundwater. While legal and institutional factors may presently help constrain irrigation adoption in some areas, changes in these regulations could substantially affect developments.

3.6.2 Projections

A range of projections of irrigated acreage and peak water use are presented in Table 3.7. In a number of cases the original projections were made by river basin or by state rather than by the exact areas within the ORBES boundaries. An effort has been made, however, to adjust the figures to reflect just the developments within the ORBES region. The values presented give an idea of the wide range in projections in addition to the relative irrigation possibilities in the basin.

The acreage projections have been taken from a number of sources, and are briefly described below. Materials were received from the files of the Soil Conservation Service (SCS) of the U.S. Department of Agriculture which are products of a nationwide study of irrigation being undertaken by the technical work group (TWG) of an interagency task force which also includes the Department of Interior and the Environmental Protection Agency (34). The materials furnished comes from survey data supplied by experts in all states in the ORBES region except Kentucky, for which no survey data were available. These surveys are excellent sources of data on present and projected irrigation practices in the states. Another important source of irrigation data is the 1974 Census of Agriculture (35). This source gives county by county figures on present irrigation.

Illinois. Different projections of irrigated acreage in Table 3.7 have been derived as follows:

Case 1 (45,500 acres) is an estimate of 1974 irrigated acreage in the ORBES counties from the Census of Agriculture (35). Nearly 19,000 of these acres were in Mason county, a county noted for its relatively sandy soil. Kankakee county had the next largest amount of acreage, with about 7,500 acres. Other leading counties were Lawrence (2,150 acres), Tazewell (1,900 acres), Henderson (1,700 acres) and Madison (1,160 acres). The 1974 Census reported roughly 54,000 irrigated acres in the entire state. The more recent TWG survey (34) reports 68,000 acres for the state.

Case 2 (200,000 acres) is a rough estimate for the ORBES counties in the year 2020 based on a straight-line projection for the entire state (21, p. 41) which projects a state total of about 250,000 acres. Projected acreage in Mason county in 2020 is 90,000 acres, or half the total irrigable land in that county.

Case 3 (800,000 acres) is an estimate for the ORBES counties, based on a potential of 1 to 1.2 million irrigated acres in the entire state at some point in the future (27, 29). Other sources go as far as suggesting that as many as

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PAGE NUMBER

EPA-287 (Cin.)
(4-76)

TABLE 3.7 PROJECTIONS OF IRRIGATION IN THE ORBES REGION

State[1]	Acreage	Peak Week Withdrawals (mgd)[2]	Annual Use[3] (Thousand Acre-Ft.)
Illinois			
Case 1	45,000	260	Not Available
Case 2	200,000	1,200	Not Available
Case 3	800,000	4,700	Not Available
Indiana			
Case 1	20,000	120	19
Case 2	61,000	360	57
Case 3	220,000	1,300	140
Case 4	1,500,000	8,700	Not Available
Kentucky			
Case 1	20,000	120	Not Available
Case 2	32,000	190	28
Case 3	64,000	370	55
Ohio			
Case 1	20,000	120	Not Available
Case 2	54,000	310	32
Case 3	270,000	1,600	210
Pennsylvania			
Case 1	1,600	9	Not Available
Case 2	5,100	30	Not Available
Case 3	11,000	64	Not Available
West Virginia			
Case 1	2,300	13	Not Available
Case 2	6,000	35	Not Available
Case 3	8,400	49	Not Available

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[1] ORBES portion of states only.
[2] 1 million gallons per day (mgd) = 1.549 cubic feet per second.
[3] From different sources than those for peak week use figures.

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EPA-287 (Cin.)
(4-76)

3 million acres in the state may be irrigated ultimately (19, 29). Total Illinois farm acreage in 1974 was reported as roughly 24.4 million acres (35).

Groundwater is presently the dominant source of water for irrigation in Illinois. According to the TWG survey (34), roughly 66,000 of the 68,000 irrigated acres received groundwater; only about 2,200 acres used surface water supplies. Projections in the survey (34) suggest that future developments will use 75% groundwater and 25% surface supplies.

Indiana. The following cases are presented in Table 3.7:

Case 1 (20,000 acres) is an estimate of irrigated acreage in the ORBES region (36). According to the 1974 *Census*, irrigation in the ORBES counties is somewhat less (about 17,200 acres). The *Census* figures may be on the low side, however. The more recent SCS data reports that roughly 56,000 acres in the entire state receive irrigation; the 1974 *Census* reported only about 33,400 for the state. Much of Indiana's present and projected irrigation, it should be emphasized, is expected to occur in the northernmost counties, which are not included in the ORBES region. Of the counties in the ORBES region, Jasper county was reported to have about 3,900 acres irrigated in 1974, and Knox county was reported to have 1,650 acres (35). These figures may have increased since then.

Case 2 (65,000 acres) is a projection for 2020 for the ORBES counties based on a straight-line extrapolation of recent trends (36). Those projections estimate roughly 91,600 acres for the entire state for 2020. The TWG survey reports that between 100,000 and 144,000 acres in the state could now be irrigated to maximize production.

Case 3 (220,000 acres) is the estimated economic potential for irrigation in the Wabash River Basin (which includes part of Illinois and excludes part of Indiana) in the year 2000 (3).

Case 4 (1.5 million acres) is a projection of the amount of economically feasible irrigated acreage by 2020 in the Wabash River Basin (17). Similar estimates of 1 to 1.5 million acres for the entire state are based on the existence of potentially droughty soils (28). These latter estimates are for the entire state, and therefore include the northernmost counties which are outside of the ORBES region.

Groundwater presently accounts for 40,000 of the 56,000 irrigated acres in the state, according to the TWG survey (34). Surface water supplies serve as the water source for the remaining acreage. According to the survey 85% of future irrigation projected by the SCS in Indiana will be supplied by groundwater sources. Only 15% will use surface supplies.

Kentucky. The following cases are presented in Table 3.7:

Case 1 (20,000 acres) is based on the *Census of Agriculture* figures for 1969 (25). According to the more recent edition of the *Census* (35) only 11,000 acres were irrigated in 1974.

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

Case 2 (32,000 acres) is a projection of economically feasible acreage in the Kentucky, Salt and Licking River Basins in 1980 (3). This estimate includes most of the irrigated acreage in Kentucky projected by that reference for the state, except for the portion which falls into the Ohio River Main Stem subbasin.

Case 3 (64,000 acres) is a projection of economically feasible acreage in the Kentucky, Salt, and Licking River Basins in the year 2000 (3).

Unfortunately, Kentucky did not respond to the TWG survey, so no breakdown into surface and groundwater sources for irrigation was possible.

Ohio. The following cases are presented in Table 3.7:

Case 1 (20,000 acres) is the estimated total for the ORBES portion of the state based on figures for irrigated water use in 1975 (7). According to the Census of Agriculture the entire state irrigated 22,000 acres in 1974. Of this sum, roughly 12,600 were accounted for by ORBES counties. The Census figures may be on the low side, however. According to the TWG data (34) over 48,000 acres were irrigated in recent years in the entire state. The largest users in southeastern Ohio in 1974 were Stark (1,400 acres) and Washington (450 acres) counties, according to reference 26. According to the Census (35), Champaign, Clark, Hamilton, Medina, Miami, Portage, and Summit counties were relatively large users, with several hundred irrigated acres each.

Case 2 (54,000 acres) is the sum of projections of economically feasible acreage in the Muskingum, Scioto, and Little Miami River Basins in 1980 (3). This estimate does not include acreage in the Ohio River Main Stem region. According to the TWG survey, a total of 100,000 acres in the state could be irrigated at present (34).

Case 3 (270,000 acres) is a projection for 2000 for the same region as Case 2 (3).

Surface and ground supplies presently serve 32,000 and 16,000 acres, respectively, according to the SCS. In the future the TWG survey suggests that developments will use equal amounts of ground and surface supplies.

Pennsylvania. The following cases are presented in Table 3.7:

Case 1 (1,600 acres) is based on 1974 acreage reported in the Census of Agriculture (35) for the ORBES region. The TWG survey (34), which were completed for sub-basins for Pennsylvania, are consistent with this figure, reporting 1,000 acres under irrigation for a similarly defined region. The surveys projected little increased acreage in the near future.

Case 2 (5,100 acres) is based on converting irrigation water use projections supplied by the state for watersheds and river sub-basins (8) into rough acreage figures for the year 2000. The state supplied projections for the years 1980 and 1990, and it was assumed here that the growth in acreage between these two dates would occur again between 1990 and 2000. This projection suggested roughly 29.5 million gallons per day of water use, which at 1.5 inches per peak week was converted into roughly 5,100 acres.

EPA-287 (Cin.)
(4-76)

Case 3 (11,000 acres) is based on estimates for the Allegheny, Beaver, Monongahela, and Upper Ohio Main Stem River Basins from reference 3 of economically feasible irrigation in the year 2000. The estimates also include the Pittsburgh SMSA region which is reported separately in that reference. Only portions of the estimates for above river basins have been included in the figure of 11,000, because portions of those basins are not in the ORBES portion of Pennsylvania.

Only surface water is used in the ORBES portion of Pennsylvania for irrigation according to the TWG survey (34).

West Virginia. The following cases are reported in Table 3.7:

Case 1 (2,300 acres) is an estimate of irrigation in the state suggested by reference 31. This figure is close to the 1,500 reported by the Census for 1974 (35). According to the TWG survey 5,300 acres are presently irrigated in West Virginia.

Case 2 (6,000 acres) is based on an estimate from reference 3 and is modified downward, due to the rough estimate of 4,500 acres in the year 2000, supplied by reference 31. Note that the TWG records nearly this much acreage at present.

Case 3 (8,400 acres) is based on an estimate from reference 3 for the year 2020. As with Case 2 this projection is based on the economically feasible irrigation in portions of the Kanawha, Monongahela, and Ohio River Main Stem Basins. The respondent to the TWG survey (34) suggested that over 156,000 acres "should be irrigated to maximize production," but indications are that little of this potential acreage will be irrigated because of inavailability of sufficient water or prohibitive costs of developing such water sources (32).

Surface water sources supply 4,800 of the 5,300 acres presently irrigated according to the TWG survey. Groundwater supplies the remaining acreage. Future irrigation is expected to be supplied 80% by surface and 20% by groundwater sources according to the TWG data.

3.6.3 Water Application Rates

Two types of water withdrawal estimates are presented in Table 3.7. Peak week levels have been calculated in million gallons per day (mgd) based on irrigation of all acreage at a level of 1.5 inches over a seven-day week. This calculation is described below. Where projections of water use are available (3, 36) they are also presented. Figures from these other sources are presented here in acre-feet per year, but it should be noted that almost all irrigation occurs over the summer months. Therefore, the levels of acre-feet are low in the sense that they average the water use over the entire year.

Because irrigation in the region is supplemental, in order to relieve drought conditions, large year to year variations in the extent of irrigation can be expected. It is reasonable, however, to expect some correlation between critical crop droughts and river low-flows. Note that extensive irrigation during low-flows could cause special impacts.

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

The quantity and timing of irrigation in the basin will vary because of crop, soil, and climatic differences. In a given area, however, corn and soybeans would require similar amounts and timing of irrigation. Since these are among the most important crops in the ORBES region, they are central to the derivation of peak week irrigation rates.

For corn, the critical period in Illinois (and presumably most of the basin) is typically the last two weeks of July—i.e., about 65 days after seedling emergence—when the plants are undergoing silk emergence. At this time the plants have the greatest water need, and this is also the time when rainfall is least probable. During each of these two weeks as much as 1.5 inches of water might be applied by irrigation. In West Virginia, a figure of two inches every two weeks has been suggested as being a more reasonable rate (31). Although the figures in Tables 3.7 are based on the 1.5 inch/week rate, the water use figures could be converted to other average application rates.

Total annual application rates vary over the region and differ among crops and references. Basically, however, total application of six inches to one foot are most common. In Illinois, total water application for corn may be in the range of one foot, half of which might come in one month (27). The TWG survey (34), however, suggests the rate may be closer to eight inches. The annual application rate for corn in Indiana is reported to be ten inches presently (34). Vegetable crops in these two states receive similar applications of water (34). In Ohio, most of the irrigation is for vegetable and other horticultural crops, and is estimated to be a total of six inches per season. Corn and other row crops in Ohio also receive six inches per season. Application rates in Pennsylvania are somewhat lower, with vegetable crops receiving only four inches of irrigation, while the smaller orchard crop acreage receives roughly seven inches (34). In West Virginia the annual application rates are six inches for corn and are four inches for fruits and vegetables.

Illinois's Plan for Action (19, p. 233) presents tables which may be useful to readers with special interests in irrigation. These tables show the percentage increase in corn and soybean yields, the amount of water application in inches, and the frequency of this requirement in terms of the number of years out of twenty, for different regions of the state. The tables suggest, for example, that in much of the ORBES region increases of corn yield of 20% or more in about five years out of twenty could be achieved by applying four to five inches of water. Bean yield increases of similar magnitude would require generally more water and would be limited to the more southern portions of the state. In using such tables one might be concerned with both the average water application rate as well as the more infrequent rates of particularly droughty years.

3.6.4 Consumption

Water use for irrigation is highly consumptive due to large losses from transpiration and evaporation. According to Murray and Reeves (11,13), more than 90% of the irrigation water in the ORBES region may presently be consumed. They note that their data for some regions may be poor, but even the lowest consumption rate in the nation for a large region is above 33%. The average rate of consumption of irrigation water in the U.S. was 56.4% in 1975 (11) and 59% in 1970 (13).

The range of consumption figures presented in Table 3.8 is based on peak week application of 1.5 inches to all the acreage shown in parentheses. The national average consumption rate of 56.4% has been used to generate the consumption estimates. The low consumption figure is based on data for irrigated acreage in recent periods and assumes no additional development. The moderate and high estimates correspond to significant increases of irrigated acreage and are provided only to suggest a possible range of consumption figures. The acreage estimates in Table 3.8 are based on the acreage figures presented in Table 3.7; however, in many cases the figures in Table 3.8 are lower than in Table 3.7. The lower estimates reflect the observation that it is doubtful that all acreage in the state would be irrigated simultaneously.

The rough estimates in Table 3.8 indicate that irrigation development could entail significant levels of water consumption, relative to the total consumption estimates for municipal and industrial uses suggested in Table 3.5. Irrigation demands would be met from some combination of groundwater and surface water sources. Depending on the extent to which surface water is used, the impact (in conjunction with that of other uses) on the 7-day 10-year low flows could be significant. Extensive groundwater utilization should be studied carefully because of the inter-relationship with surface water and because safe-yield estimates are not known in many areas.

TABLE 3.8 WATER CONSUMPTION IN 2000 FOR IRRIGATION IN COMPARISON TO OTHER WATER USES[1]

State[2]	Irrigation Consumption (mgd)[3] Low	Moderate	High	Projected Municipal and Industrial Consumption (mgd)[4]
Illinois	110 (33)	330 (100)	660 (200)	220
Indiana	66 (20)	330 (100)	660 (200)	200
Kentucky	66 (20)	130 (40)	200 (60)	220
Ohio	66 (20)	490 (150)	820 (250)	530
Pennsylvania	5.3 (1.6)	17 (5.1)	36 (11)	480
West Virginia	7.6 (2.3)	20 (6)	28 (8.4)	340
Total	320 (97)	1,300 (400)	2,400 (730)	1,900

---

[1] Irrigated acreages, in thousands of acres, are given in parentheses.

[2] ORBES portions of states only.

[3] 1 million gallons per day (mgd) = 1.549 cubic feet per second (cfs).

[4] Projected total consumption estimates from Table 3.5.

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4. WATER CONSUMPTION UNDER DIFFERENT COOLING ALTERNATIVES

4.1 INTRODUCTION

One factor to be considered in a water quality assessment of impacts from power plants is the water consumption of the proposed energy facilities. This section will survey estimates of water consumption by power plants with: 1) once-through cooling, 2) wet cooling towers, 3) cooling ponds, and 4) spray ponds. (These alternative technologies are described in various references, e.g., references 2 and 10.) The results are shown in Tables 4.1 to 4.4. References and major assumptions accompany each estimate. Based on the date and depth of the analysis behind each estimate, the authors compiled Table 4.5 which summarizes the survey results and estimates used for the ORBES generic plants.

4.2 ONCE-THROUGH COOLING SYSTEMS

All the estimates in the literature reviewed base an estimate for water consumption from once-through on a formula from reference 1. They assume the amount of heat lost by evaporation after once-through cooling is 50 percent of the heat discharge, i.e.,

$$Q_e = .5 \frac{H_r}{L}$$

where Q_e = quantity of water evaporated (lb/hr)

H_r = heat rejection rate (BTU/hr)

L = latent heat of vaporization (BTU/lb)

The consumptive water loss may also be written as a function of ΔT, the temperature rise of the cooling water:

$$Q_e = \frac{\Delta T}{2L} Q$$

where Q = total water withdrawal

It should be noted that design of cooling systems and discharge structures, effluent and ambient flow quantities, and meteorological conditions all affect Q_e.

Since ORBES scenarios specify once-through cooling only on large rivers, the Mississippi and Ohio Rivers, a large hypothetical river of 20,000 cfs was assumed for the purpose of estimating once-through consumption. The flow, stream velocity, width, depth, and meteorological conditions were assumed

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TABLE 4.1 ONCE-THROUGH

Reference	Consumption cfs/1000 MW	Major Assumptions
FPC (9)	10-12 cfs (coal) 15-17 cfs (nuclear)	
Malina and Moseley (10)	7.4-11 cfs	1) Developed by authors using Ref. 11

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TABLE 4.2 COOLING TOWERS

Reference	Consumption cfs/1000 MW[1]	Major Assumptions
USEPA Nomographs (12)	15-16 cfs (coal) 24 cfs (nuclear)	1) Natural draft 2) Operating cond. seem insig. 3) Load factor - 100% 4) Efficiency: coal-fired--36% nuclear--32%
USEPA Nomographs (12)	16-17 cfs (coal) 25 cfs (nuclear)	1) Efficiency: nuclear--32% 2) Mech. draft 3) Load factor = 100% 4) Efficiency: coal-fired--36%
H. Gold D. J. Goldstein D. Yung (4)	21.5 cfs	1) Kind of tower not told 2) 100% load 3) 77.5% of heat rejected is lost through evaporating 22.5% of heat rejected is lost by conduction and convection 4) Condenser inlet temperature 92F 5) Range = 22 F 6) Tower inlet water temperature = 114 F
Guy R. Nelson (3)	14.7 cfs (coal 24 cfs (nuclear)	1) Plant type and efficiency consumption (cfs): coal-fired, 38% –> 14.7 cfs coal-fired, 36% –> 16 cfs Nuclear, 32% –> 24 cfs 2) Load factor = 100% 3) 75% of rejected heat loss is due to evaporation, 25% of rejected heat loss is due to conduction and convection 4) Used 1000 (BUT/1b) (Latent Heat of Vaporization) 5) Neglect drift

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EPA-287 (Cin.)
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TABLE 4.2 (continued)

Reference	Consumption cfs/1000 MW	Major Assumptions
Leung and Moore (5)	12.7 cfs/750 MW	1) 100% loading 2) 750 MW 3) Condenser heat load = 3500×10^6 (BTU/hr) 4) Not clear nuc or coal Navajo plant Page Ariz. 5) Mech. tower 6) Makeup 6040 gpm at 90 F
E. V. Giusti E. L. Meyer (13)	25 cfs	1) nuclear 2) 80% of rejected heat loss is due to evaporation 3) 100% load 4) 32% efficiency
FPC (9)	26-28 cfs (coal 35-40 cfs (nuclear)	1) Heat rate: coal—9000-9500 (BTU/kwhr) nuc—10000-10500 (BTU/kwhr)
Parker and Krenkel (14)	17-34 cfs	1) Mech. draft and natural draft 2) Most examples in this reference listed consumption estimates in the lower end of this range
Malina and Moseley (10)	28 cfs	1) Wet towers—mechanical draft 2) Developed by authors using Ref. 2
Leung (15)	(a) 23 (b) 15.4 (c) 15.4 (d) 18.8	1) Avg. wet-bulb temp = 57 F 2) Relative humidity = 56% 3) Drift = .005% of the circulating rate (a) Nuclear (LWR) heat rejection rate = 6.89×10^9 (BTU/hr) (b) Fossil-fueled heat rejection rate = 4.59×10^9 (BTU/hr) (c) Nuclear (HTGR) heat rejection rate = 4.59×10^9 (BTU/hr) (d) Nuclear (LMFBR) heat rejection rate = 5.59×10^9 (BTU/hr)

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[1] For Tables 4.1 to 4.5 units will be cfs/1000 MW with 100% loading factor, unless otherwise indicated.

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TABLE 4.3 COOLING PONDS

Reference	Consumption cfs/1000 MW			Major Assumptions
	Year	Coal	Nuclear	
FPC (9)	1980 1990	16 14	22 20	1) 1000 MW plant at 100% loading 2) Coal heat rate= 1980—9500 (BTU/kwhr) 1990—9000 (BTU/kwhr) Nuclear heat rate = 1980—10500 (BTU/kwhr) 1990—10000 (BTU/kwhr)
Nomographs (12)	22-29 cfs (coal) 33-43 cfs (nuclear)			1) Extremes due to (1 acre/MW)-> lower evaporation rate (2 acre/MW) ->higher evap. rate 2) 60% rel. humidity 3) 70% cloud cover 4) Wind mph = 8 5) Range = 20 F 6) Based on a 1970 paper by Hauser, L.G. and K.A. Oleson, "Comparison of Evaporative Losses in Various Condensor Cooling Water Systems," presented at 32nd Annual American Power Conference Meeting, 1970 7) Fossil-fueled plants reject 50% less heat to the cooling water than do nuclear plants
Eggen and Livengood (16)	(a) 66 cfs (b) 35 cfs			(a) 1) condenser flowrate 2154 cfs 2) 2 (acres/MW) (b) average meteorological conditions (a) and (b) based on Ref. 17.
Christianson, A.G, *et al.* (6)	55 cfs			1) Chicago meterology assumed 2) Inlet pond temp. of 115 F 3) 1000 MW nuclear plant
Littleton Research and Engineering Corp. (17)	a) 55 cfs b) 71 cfs			1) 2000 MW plant 2) a) 1 (acre/MW) b) 2 (acre/MW) 3) During summer months June-Aug. 4) Average annual precipitation of 40" is included; consumption = evaporation - precipitation
Malina and Moseley (10)	7.4-11 cfs			1) Developed by authors from Ref. 11.

EPA-287 (Cin.)
(4-76)

TABLE 4.4 SPRAY PONDS

Reference	Consumption cfs/1000 MW[2]	Major Assumptions
Nomographs (12)	a) 15 cfs (coal) 26 cfs (nuclear)	1) Closed-cycle 2) (a) Condenser rise = range = 15 F
	b) 14 (coal) 22 (nuclear)	(b) Condenser rise = range = 25 F

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[2] Based on Refs. 18 and 19, the consumption for spray ponds is 65-80% of what it would be under quiescent conditions.

TABLE 4.5 WATER USE COEFFICIENTS FOR EVALUATING ORBES SCENARIOS[3]

Cooling Towers	Withdrawal (cubic feet/second)	Consumption (cubic feet/second)
Coal plant (650 MW with scrubber)	19	13
Coal plant (650 MW without scrubber)	17	10
Nuclear (1000 MW)	43	27

Once-Through Cooling	Withdrawal (cubic feet/second)	Consumption (cubic feet/second)
Coal plant (650 MW with scrubber)	1020	10
Coal plant (650 MW without scrubber)	1020	7.5
Nuclear (1000 MW)	2160	19

[3] Based on calculations described in section 4.2 and on estimates given in Reference 8. Estimates are for a 100% load factor. In evaluating ORBES Scenarios, load factors of 50% and 65% were assumed for coal-fired and nuclear plants, respectively.

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based on typical conditions in the middle reaches of the Ohio River during a 7-day 10-year low-flow period. Temperature profiles were computed for two cases using the energy balance equations of Edinger and Geyer (2). One case assumed a coal-fired scenario plant and the other case assumed a nuclear scenario plant. In each case, the energy balance included an estimate of heat loss due to evaporation in different segments of the hypothetical river. The estimates of heat loss were then used to compute the evaporative water losses in each reach. The losses from all reaches were combined, producing the estimates given in Table 4.1. These estimates are based on many simplifying assumptions; the actual consumptive losses would depend on the appropriate steam parameters in any given case. Additional research is needed in this area.

4.3 EVAPORATIVE COOLING TOWERS

Three heat dissipation mechanisms in a cooling tower are convection, conduction, and evaporation. These mechanisms share the load of heat dissipation in different amounts depending on tower design and operation, power plant design and operation, and meteorological conditions. Usually, about 75% of the heat load is attributed to evaporation (3, 4). Weather conditions or seasonal differences do not change the evaporation rate significantly. For example, Leung (5) used a heat and mass balance to compute the monthly evaporation rate for an Arizona power plant. The maximum monthly evaporation rate departed from the average annual rate by about 1 cfs. This study performed similar computations for locations within the ORBES region and similar results were obtained.

One basic formula for estimating cooling tower consumption (3.4) is:

$$Q_e = \frac{H_r \alpha}{8.33 L (60 \frac{\text{min}}{\text{hr}})}$$

where α = fraction of heat lost through the process of evaporation (The value, α, can range from 0.6 to 0.9. The commonly used value is approximately 0.75. (1, 3, 5, 6),

H_r = heat rejection rate (BTU/hr),

Q_e = evaporation rate (gpm),

L = latent heat of vaporization (BTU/lb).

4.4 COOLING PONDS

Two methods have been used for estimating water consumption by cooling ponds. First, the energy budget method (see reference 2) requires a complete evaluation of each component of energy transfer across the water surface. There are difficulties in measuring certain components such as atmospheric radiation, long-wave radiation from the water body and energy storage. Small variations in terms like pond temperature may result in large variations in the amount of evaporated water computed by this method (16).

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The second method is based on mass transfer equations of the following form:

$$H_e = (a + bw)\ (e_s - e_a)$$

where H_e = heat loss through evaporation (BTU/ft^2 · day)

a, b = empirical constraints

e_s = vapor pressure of saturated air at the pond water temperature, (in Hg)

e_a = vapor pressure of ambient air, (in Hg)

H_e has been estimated in several studies as described in reference 2:

from Lake Hefner (near Oklahoma City, Oklahoma) studies,

$$H_e = 11.4w(e_s - e_a)\ \text{BTU/ft}^2 \cdot \text{day}$$

from Lake Colorado City (Texas) studies,

$$H_e = 16.8w\ (e_s - e_a)\ \text{BTU/ft}^2 \cdot \text{day}$$

by Meyer

$$H_e = (73 + 7.3\ w)\ (e_s - e_a)\ \text{BTU/ft}^2 \cdot \text{day}.$$

Harbeck (7) has provided a shorter computational method. It involved estimating N, a mass-transfer coefficient graphically, and using:

$$Q_e = NW\ (e_s - e_a)$$

to estimate the daily evaporation rate. The additonal evaporation caused by the heat input from a power plant is also estimated graphically as a function of pond surface temperature and wind speed.

Note that the evaporative water loss is not the consumptive loss due to a power plant. In order to estimate the consumptive loss resulting from the presence of the power plant, factors that should be included are:

1. Water loss from seepage;
2. Water gain from direct precipitation, runoff, and infiltration;
3. A distinction between the amount of water that would evaporate without the presence of the power plant versus the additional water that evaporates resulting from the presence of the plants;
4. Nature of mixing of the lake water and plant effluent.

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

4.5 OVERVIEW

This study used water consumption estimates based on material flow balances of power plants (8) adopted by ORBES as generic plants. (The unit coal-fired plant capacity was scaled down from 1000 MW to 650 MW.) Consumption due to cooling towers and limestone scrubbers was considered. Table 4.5 summarizes the estimates used in this study of consumption and withdrawal for different power plants and cooling systems.

EPA-287 (Cin.)
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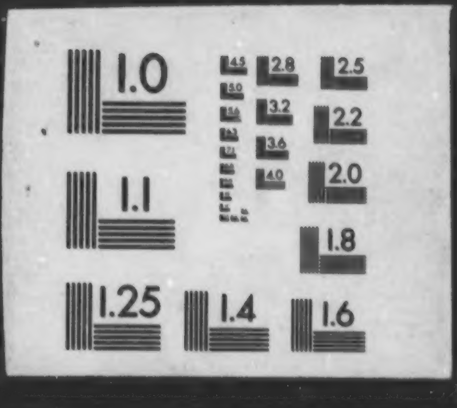
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EPA-287 (Cin.)
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5. WATER AVAILABILITY: A GEOGRAPHICAL ANALYSIS

5.1 INTRODUCTION

This chapter presents an overview of the distribution of water available for power plant cooling in the ORBES Phase II region in the year 2000. The material presented here is designed to be useful to planners without special expertise in water resources, who would like to consider water availability in their development of hypothetical plant location scenarios.

The basis for the material presented here is a computer program, CORT, (from COnsumption RaTio) which among other features calculates the numbers of power plants which may be sited along the region's rivers without total municipal, industrial, and power water consumption exceeding certain consumption limits. The consumption limits are stated in terms of percentages (e.g., 5% and 10%) of the rivers' low-flows.

In this chapter, following a discussion of the major assumptions underlying these calculations, maps are presented which convey the general geographical or spatial aspects of water availability in the ORBES region. While scheduled plant additions and removals are considered in this analysis, the analysis is based on water use prior to the siting of any ORBES scenario plants. The presented material, therefore, can be used by planners in both the design and impact analysis of scenarios.

In addition to providing general insights into water availability, the analysis presented here may alert planners to specific "trouble" areas. These areas may be more susceptible to significant impacts due to power plant cooling water use than areas with larger river flows and/or lower projected municipal and industrial demands. Information showing relative deficiencies of available water may encourgage scenario designers to take two possible approaches. First, planners may avoid siting plants in areas which appear to be relatively deficient in surface-water. This approach might be undertaken to concentrate ORBES research on areas which may be more "realistic" sites from the viewpoint of actual future development by power companies. Alternatively, planners may choose to locate some plants in potential trouble areas. In this case, the information provided here may suggest that special attention be paid to water-related environmental impacts in these areas. Special water-related concerns could include impacts on aquatic biota and water quality caused by decreased river flows, impacts associated with groundwater depletion, and impacts of water storage in reservoirs.

Although the analysis presented here may suggest problems with locating power plants in areas relatively deficient in surface-water, siting of plants in these areas is by no means precluded. One reason is that in this analysis the power plant water consumption (i.e., evaporation) figures assumed for future plants (but not necessarily scheduled additions) are based on a specific

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

cooling technology, i.e., evaporative cooling towers. Planners should note that other cooling technologies exist including once-through cooling, dry towers, and combinations of wet and dry towers, as well as innovative processes which use waste heat embodied in the cooling water. Also, new technologies could be developed over the coming decades. A second major factor which could affect plant location is the possibility of water storage, such as in the form of reservoirs. In some areas where river low-flows are insufficient to maintain water availability for power plant cooling as well as other uses, reservoirs might be constructed to provide cooling water for power plants during low-flow periods.

5.2 MAJOR ASSUMPTIONS

In addition to the points noted above, a number of other important assumptions underlie the calculations presented in this chapter. Understanding of these assumptions is helpful because it gives planners using these materials a sense of their strengths and shortcomings. In general because of the assumptions made here, users should be cautioned to interpret the figures presented in a broad, relative sense, rather than as specific, exact numbers.

5.2.1 Power Plant Water Use

The maps which follow present the number of "plant equivalents" which may be sited along the ORBES region rivers while the total of municipal, industrial and power plant water use does not exceed 5% or 10% consumption of the 7-day 10-year low-flow. A unit plant equivalent is defined here as a 650 MW coal-fired power plant operating at 50% load capacity. The plant is assumed to employ cooling towers which consume approximately 0.02 cubic feet per second (cfs) per megawatt (MW) generated. At 50% load, therefore, a unit plant equivalent is assumed to consume approximately 6.5 cfs (325 x .02).

Other figures used in this analysis for power plant water withdrawals and consumption are presented in Table 5.1. These figures are rounded values based on figures presented in Chapter 4 (see especially Table 4.5). For this investigation it is assumed that all planned and conjured (i.e., scenario) coal-fired plants utilized scrubbers. Nuclear plants are assumed to consume water at the rate of .027 cfs/MW. Actually, plants using recycled plutonium in addition to uranium may use slightly less (Table 4.5).

While the plant equivalents presented in the maps represent a specific type of plant (650 MW coal-fired with wet towers, operating at 50% load capacity), the figures presented can be easily adjusted to analyze other types of plants. For example, in order to analyze a 1000 MW nuclear plant with wet towers operating at 65% load, the numbers presented would be multiplied by .57 which equals the ratio of load factors (.50/.65) times the ratio of consumption per megawatt of coal plants to consumption per MW for nuclear plants, which is shown by Table 5.1 to be (.020/.027). Because of the higher consumption rate for nuclear plants, therefore, fewer nuclear plants could be sited and still not exceed the consumption levels of 5% or 10% presented in the maps. Higher load factors, such as 75%, would be analyzed by multiplying the number of plant equivalents by the appropriate ratio, e.g., .50/.75 or .67.

TABLE 5.1 POWER PLANT COOLING WATER FIGURES[1]

Cooling Technology	Withdrawals	Consumption
Coal-fired Plants		
Wet towers	.0292	.020
Once-through	1.569	.0154
Ponds	.0585	.0292
Nuclear Plants		
Wet towers	.043	.027
Once-through	2.16	.019
Ponds[2]	.086	.043

---

[1] In cubic feet per second (cfs) per megawatt (MW) of electricity generated.

[2] Ponds were divided into two categories: (1) those located on major rivers and assumed to withdraw river water, and (2) ponds assumed to function as reservoirs and which would not affect 7-day 10-year low flow. Figures for the first type of ponds are presented here; the second type are assumed to have zero consumption for the CORT analysis.

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EPA-287 (Cin.)
(4-76)

5.2.2 Scheduled Additions and Removals

The numbers of plant equivalents shown in the maps represent possible additions beyond scheduled additions and removals. These possible additional plants might be scheduled by ORBES scenarios, for example.

Data on scheduled additions and retirements from 1971 through the year 2000 were obtained from reference 1 and from the ORBES scenarios, which listed planned additions from 1976. In addition to giving the location, size and fuel of the relevant plants, this reference also reports the cooling technologies of almost all the plants. In the few cases where data are missing on cooling technologies, reasonable assumptions were made here based on the geographic location of the plants concerned and the technologies used by neighboring plants. Almost all additions will use wet towers or ponds, though a few will use once-through. Once-through was used by almost all of the removals, though a couple used other technologies. (Because the 7-day 10-year low flow data were assumed to represent 1970 figures, plants added or removed from 1971 on were considered by the analysis. Therefore, in addition to the ORBES scenario "planned" plants, additions include plants which came on line from 1971 until the present. Removals from 1971 and into the future as scheduled in reference 1 were also considered.)

5.2.3 Municipal and Industrial Water Use

Projected water withdrawals and especially consumption by municipalities and industries have been included in this examination of water availability. Where the maps show negative or zero plant equivalents, this indicates that municipal and industrial demands together with scheduled power plant additions will consume 5% or 10% of a river's present 7-day 10-year low flow.

County projections of municipal and industrial withdrawals described in Chapter 3 were used as input for the CORT program. The program then applied consumption factors to the municipal and industrial withdrawal figures. As was discussed in Chapter 3, the figures .20 and .10 are regarded here as the best estimates of municipal and industrial consumption as a fraction of withdrawals. Note that industrial withdrawals were projected here to increase proportionately with earnings (though they are actually more likely to remain fairly constant) in order that increasing industrial consumption could be calculated, as discussed in Chapter 3.

Parametric analysis of different consumption factors was also tried with CORT, in addition to using the figures cited above. In order to examine a "low" estimate of municipal and industrial consumption, factors of .15 and .06 were used for municipal and industrial consumption, respectively. Municipal and industrial consumption factors of .23 and .11 were used to generate a "high" consumption estimate. These alternative factors are discussed in Chapter 3.

While only plant equivalent figures for the best set of estimates (.20 and .10) are presented in this chapter, it is believed that the figures presented here give a good description of consumptive impacts. In only a few instances, discussed below, would one be wise to consider other factors.

EPA-287 (Cin.)
(4-76)

Furthermore, when consumption ratios are being examined (as opposed to plant equivalents) the type of printout supplied by CORT makes it very easy to examine the impact of lower or higher consumption factors, without explicit and extensive parametric analysis. When analyzing scenarios the printout gives the consumption ratios--the fraction of low-flow consumed by reach--for municipal, industrial, and power consumption separately and then totaled. Therefore, if one wishes to consider an industrial consumption factor of 6% rather than 10% for a given reach, one can simply multiply the industrial consumption ratio in the printout by .6 and subtract the difference between the original and new industrial consumption ratios from the total consumption ratio for the reach.

As noted above there may be a few regions where one might wish to consider using a lower industrial consumption factor than the 10% figure which was assumed to be best for the region as a whole. These regions include the Youngstown, Ohio area, which affects the one reach of the Mahoning River (in the Beaver Basin) and the Charleston, West Virginia area, reach 2 of the Kanawha River. The Pittsburgh area, especially reach 2 of the Monongahela River, may also be such a region, but in this area withdrawals were not simply projected using manufacturing earnings (as described in Chapter 3) but rather were projected by the state to increase at a much slower rate (reference 2; see also Chapter 3). Therefore, there is less of a chance of over-projection of industrial consumption in the Pittsburgh region than in the other two areas. At any rate, because of the very large volumes of water withdrawn in Youngstown and Pittsburgh for steel production and in Charleston for chemical production, these regions may actually consume industrial water at a rate below the national average of 10%. Finally, it should be noted that for some reaches in Pennsylvania the municipal and industrial water use was not included for upstream reaches because these data were aggregated into downstream reaches. So, for Reach 1 of the Beaver River, Reach 2 of the Monongahela River and Reach 2 of the Allegheny, the municipal and industrial components from Pennsylvania have not been included until the next reach downstream.

5.2.4 Incremental Analysis and Surface Water Ratios

The water consumption analysis performed with CORT considers only the incremental portion of municipal and industrial consumption, that is, the projected change in consumption from 1970 to 2000. It is assumed that the consumption of water in 1970 was already reflected by the river low-flows on record. This same logic means that only power plant additions and removals need to be considered as affecting water availability, and that not all existing plants need be explicitly considered.

One minor problem may arise if the 7-day 10-year low-flows occurred much prior to 1970. If so, then the growth in demand from that time--e.g., from 1965 to 1970--might mean that the next time low-flow conditions occur, the flow could be even lower than before. Still, as a first approximation the incremental assumption made here is probably reasonable.

An assumption which is probably more significant concerns the determination of the proportion of municipal and industrial water withdrawn from surface versus ground water sources. The computer program, CORT, assigned a county's municipal and industrial withdrawals to an appropriate river based on a "surface water ratio", the ratio of surface water withdrawals to total withdrawals in a county. One major assumption is that all the surface water comes from the river. Withdrawals from reservoirs and lakes, for example, are assumed to have a consumptive impact on the river associated with the county. This assumption is valid to the extent that reservoirs, lakes, river tributaries, and surface water in general are interrelated with river flows. Unfortunately, data on county water sources for municipal and industrial demands do not allow finer distinctions in terms of the source of surface water. The assumption that all surface water consumption at least indirectly affects river flow would have the effect of overstating the impact of consumption if all surface water sources in a county are not interrelated.

Use of the surface water ratio approach means that ground water use in a county will not affect river flows. This fact implies that counties which are reported as using exclusively groundwater will in effect be ignored by the analysis, because their incremental surface water demand is assumed to be zero. Scheduled additions of power plants to such counties, however, would be considered to affect surface water consumption by the analysis because power plants were not assumed to use ground water. Even if wells were reported (as for two plants in Posey county, Indiana) it was assumed here that the large amounts of water required for a power plant would affect surface water levels.

Where data were available, separate surface water ratios were calculated for municipal and industrial demands. This approach is appropriate because where river water is of lower quality, for example, municipalities may use ground water; certain industries, however, may use river water because of the large amounts of water they require.

Separate municipal and industrial surface water ratios were calculated for Ohio, based on data supplied by the USGS (3), and for Pennsylvania based on data supplied by the state's Department of Environmental Resources (2). For a number of counties in the Wabash River basin a total municipal and industrial surface water ratio was calculated based on data in the _Wabash River Basin Comprehensive Study_ (4).

The data available for the majority of the counties in the region, however, enabled calculation only of the municipal surface water ratios. These data were found in the _ORBCS_ (5) and _UMRCBS_ (6). These sources do not give a breakdown of industrial water use into surface and groundwater components. So, for all the ORBES counties in Illinois, Kentucky, and West Virginia, and a number of counties in Indiana, the industrial surface water ratios were assumed to be equal to the municipal surface water ratio. Because there may be a tendency for municipalities to use groundwater while industry uses surface water, this assumption may tend to understate the actual amount of industrial surface water demand. This assumption, therefore, may also tend to counterbalance the assumption mentioned earlier, that all surface water used in a county comes from the river under investigation. A CORT analysis was

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EPA-287 (Cin.)
(4-76)

made assuming 100% of industrial withdrawals in certain regions come from surface sources. This analysis implied little change in regional consumption ratios.

5.2.5 River Reaches

The analysis of water availability is conducted in terms of river reaches, which are portions of rivers between triangle points (▼). Power plants located in counties adjacent to rivers would presumably draw water from the nearby river.

Water consumption in the reach is applied at the triangle points. The actual reach is upstream from these points. Note that the flow at the triangle would be somewhat greater than the flow at the top or middle of the reach actually being examined. The plant equivalents shown on the maps, therefore, are valid at the triangle or below it (downstream). If a reach is allowed ten plants, for example, it would not be realistic to site them all at the top of the reach since the river flow at the upstream side of the reach is less than at its downstream border, the triangle.

Important examples of this issue are Jasper county, Indiana, and Sangamon and DeWitt counties in Illinois. The former is placed in reach 1 of the Illinois River, but the flow of the Kankakee and Iroquois Rivers in that county would be less than the flow at the triangle point in Kankakee county, Illinois. Similarly, the flow assumed for reach 7 of the Illinois River is measured in Menard county, Illinois. This flow is signficiantly greater than the flow in either DeWitt or Sangamon counties which are on two separate river branches which join in Menard county.

Clearly the location of the reach point, the triangle, has a potential effect on the flow used for the counties in the reach. Fortunately the counties discussed above did not receive scenario plant sitings; ideally, where scenario plants are sited, reaches have been carefully formulated so as not to suggest misleading results. A related problem, however, is that in some cases where reaches are formed, exact stream flow data do not exist, and values must therefore be interpolated, creating another minor source of error.

5.2.6 "Updated" Impacts

The maps presented in this chapter show the "updated" cumulative numbers of plants allowed without exceeding the 5% or 10% consumption values. If for example, a downstream reach allows a cumulative total of 10 plants, while an upstream reach would permit a cumulative total of 15 plants up to that point, the "updated" maps would indicate a total of 10 plants for both regions. The upstream locations would be constrained by the downstream bottleneck.

Computer printout is also available which shows the non-updated number of plants permitted by each reach next to the updated figures which reflect the "bottlenecks." Analysis of these printouts would allow planners to see what consumption the upstream reaches could support if the downstream "bottlenecks"

EPA-287 (Cin.)
(4-76)

were alleviated. The "updated" cumulative figures are presented in the maps here, however, because in reality the upstream reaches are constrained by the "bottlenecks."

The available printout also gives the numbers of plant equivalents which could be sited under other limiting percentages (e.g., 15%, 20%). Additional desired percentages can be calculated using CORT.

5.2.7 Ohio River Flow Data

The 7-day 10-year low-flow data used to calculate the plant equivalent values along the Ohio River main stem are based on data received from reference 7 and reported in Table 2.8 of this report. Because of the obvious importance of the main stem, calculations have also been made using the alternative lower figures supplied by reference 8 and also reported in Table 2.8.

The large differences between these flow data sets causes large differences in the numbers of plant equivalents and in the consumption ratios calculated under the two sets. Because of contemporary construction of reservoirs, the higher set of flow figures has been taken to be the primary set. This assumption is especially valid when one considers that the analysis is designed for the year 2000 and the low flows of future years are of primary relevance. Therefore, only figures using this data set are presented here.

Insight into the importance of the choice of the figures, however, can be gained by examining the figures in Table 2.8 and noting that the primary set is often more than 50% greater than the lower set for the Ohio River upstream of Illinois. This large difference is especially significant in the case of the Ohio River because it makes the difference between having consumption ratios above or below 10% for a number of reaches. While large positive plant equivalents are shown in the 10% maps for the Ohio River in this chapter, if the lower flow values had been used then much of the river would have had negative plant equivalents.

5.2.8 County Locations

In all cases where counties border on more than one river their demands have been considered to come from the larger of the two rivers. This assumption is realistic in the sense that water demands for power are more likely to come from the larger river. In this analysis only St. Clair county, Illinois, has been divided into locations associated with two different rivers (for municipal and industrial demands), and even here it will be assumed that all power plant locations will occur in the Mississippi River basin portion.

The association of three Kentucky counties with the Ohio River is also important to note. Although Pendleton and Kenton counties lie largely in the Licking River basin, they are considered to be part of the Ohio River reaches in this analysis. Similarly, Hardin county has also been associated here with the Ohio River instead of the Salt River. These decisions are most important to realize in the context of scenario evaluation, where plants sited in these three counties will be assumed to draw water from the Ohio River and not the Licking or Salt Rivers. The decision to associate these counties with the

Ohio River was made specifically because the smaller rivers do not contain sufficient low-flows to support plants, and consumption ratios greater than 1.0 (more than 100% consumption of the low-flow) would be encountered if scenario plants were sited along these smaller rivers.

5.2.9 Irrigation

In this analysis water consumption in irrigation has not been considered. The amount and location of irrigation and the source of water are all too difficult to accurately project for the year 2000. Clearly, however, extensive irrigation could compound water availability problems which may be suggested by these materials. In general, the greatest increases in irrigation are most likely in Illinois and Indiana, and to a lesser extent in Ohio. Beyond this observation the reader is referred to Chapter 3 for a discussion of irrigation projections for the region.

5.3 USE OF THE MAPS AND DATA

While a number of assumptions have been made to simplify the analysis, in general the analysis presented is believed to be a realistic and useful planning tool. As noted in the discussion above, parametric work has been carried out. Different levels of municipal and industrial consumption and Ohio River low-flows have been used in these parametric analyses. In addition, the computer program, CORT, is adaptable to examining such other issues as different load factors, plant types, and cooling technologies, so further analysis is possible. These qualities contribute to the potential realism of the analyses made possible using CORT.

Table 5.2 gives a key to reach codes as well as other symbols used on the maps. The maps then follow for Illinois, Indiana, Kentucky, Ohio, Pennsylvania, and West Virginia. Note that only the ORBES Phase II region has been considered. The only exception to this restriction is that municipal and industrial demands along the ORBES portion of the Mississippi River—from Iowa and Missouri—have also been entered into the analysis. Projections of those demands were obtained from the UMRCBS (6).

Investigators with special interest in water consumption-related issues may wish to see printout from CORT, which in addition to the figures presented on the maps contains other useful information.

5.4 COMMENTS

Extensive comments are not presented here because the best way for readers to get a feeling for the regional distribution of water resources available for power plant cooling is to briefly examine the maps. An important point must be noted, however. CORT calculates the plant equivalent figures first for all the tributary rivers in the ORBES states and then, using the tributary consumption data as input, the Ohio River main stem plant equivalent values are calculated. Thus, consumption along the tributary rivers affects the Ohio River main stem, but not vice versa.

TABLE 5.2 REACH CODES AND MAP KEY

Illinois

BM - Big Muddy R.
IL - Illinois R.
KK - Kaskaskia R.
MI - Mississippi R.
OH - Ohio R.
SN - Saline R.
WA - Wabash R.

Indiana

OH - Ohio R.
WA - Wabash R.
WH - White R.
WW - Whitewater R.

Kentucky

BS - Big Sandy R.
CU - Cumberland R.
GR - Green R.
KY - Kentucky R.
LI - Licking R.
OH - Ohio R.
ST - Salt R.

Ohio

BE - Beaver R.
GM - Great Miami R.
LM - Little Miami R.
MU - Muskingum R.
OH - Ohio R.
SC - Scioto R.

Pennsylvania

AL - Allegheny R.
BE - Beaver R.
MO - Monongahela R.
OH - Ohio R.
SU - Susquehanna R.

West Virginia

KA - Kanawha R.
MO - Monongahela R.
OH - Ohio R.

Symbols: OH-8, for example, means reach 8 of the Ohio River.

(2.1) , for example, means 2.1 plant equivalents may be located on that reach point, minus plants already located upstream.

▼ is a reach application point, where consumption of upstream users is calculated to occur.

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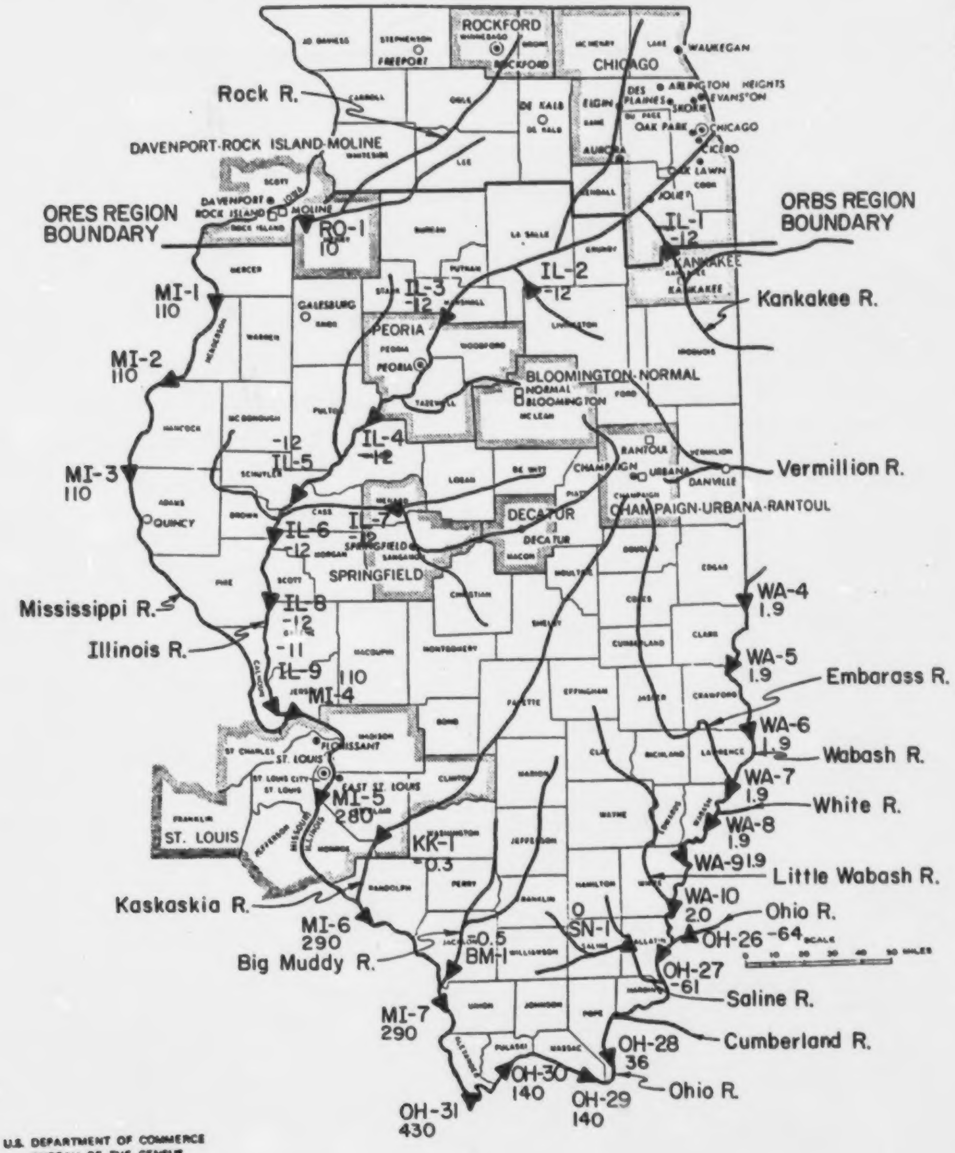
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CHICAGO
Rock R.
DAVENPORT-ROCK ISLAND-MOLINE
ORES REGION BOUNDARY
ORBS REGION BOUNDARY
RO-1
10
IL-1
-12
IL-2
-12
IL-3
-12
Kankakee R.
KANKAKEE
MI-1
110
MI-2
110
PEORIA
BLOOMINGTON-NORMAL
-12
IL-5
IL-4
-12
MI-3
110
Vermillion R.
IL-6
-12
IL-7
-12
DECATUR
CHAMPAIGN-URBANA-RANTOUL
SPRINGFIELD
Mississippi R.
IL-8
-12
Illinois R.
-11
IL-9
110
MI-4
WA-4
1.9
WA-5
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Embarass R.
WA-6
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Wabash R.
WA-7
1.9
White R.
WA-8
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WA-9 1.9
Little Wabash R.
ST. LOUIS
MI-5
280
KK-1
0.3
Kaskaskia R.
WA-10
2.0
Ohio R.
OH-26
-64
SN-1
0
MI-6
290
0.5
BM-1
Big Muddy R.
OH-27
-61
Saline R.
MI-7
290
OH-28
36
Cumberland R.
OH-30
140
OH-29
140
Ohio R.
OH-31
430
SCALE
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MAP 1. ILLINOIS: ALLOWABLE PLANT EQUIVALENTS UNDER 5% CONSUMPTION LIMITS

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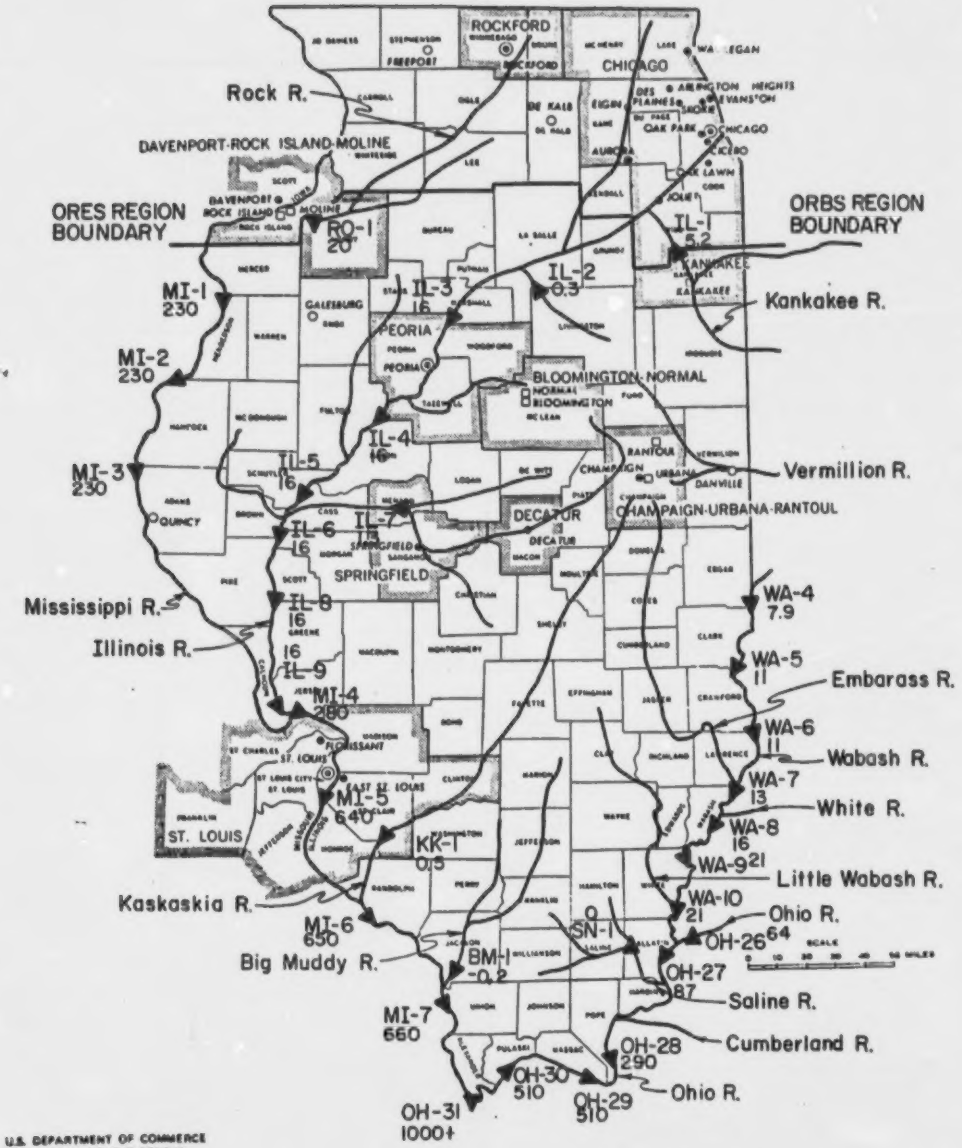
ROCKFORD
CHICAGO
Rock R.
DAVENPORT-ROCK ISLAND-MOLINE
ORES REGION BOUNDARY
ORBS REGION BOUNDARY
RO-1 20
IL-1 5.2
IL-2 0.3
IL-3 16
Kankakee R.
MI-1 230
MI-2 230
PEORIA
BLOOMINGTON-NORMAL
IL-4 16
IL-5 16
MI-3 230
Vermillion R.
DECATUR
CHAMPAIGN-URBANA-RANTOUL
IL-6 16
IL-7 15
SPRINGFIELD
Mississippi R.
IL-8 16
Illinois R.
16 IL-9
WA-4 7.9
WA-5 11
Embarass R.
MI-4 280
WA-6 11
Wabash R.
WA-7 13
White R.
MI-5 640
ST. LOUIS
WA-8 16
WA-9 21
KK-1 0.5
Little Wabash R.
Kaskaskia R.
WA-10 21
Ohio R.
OH-26 64
MI-6 650
SN-1 0
Big Muddy R.
BM-1 -0.2
OH-27 87
Saline R.
MI-7 660
OH-28 290
Cumberland R.
OH-30 510
OH-29 510
Ohio R.
OH-31 1000+
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MAP 2. ILLINOIS: ALLOWABLE PLANT EQUIVALENTS
UNDER 10% CONSUMPTION LIMITS

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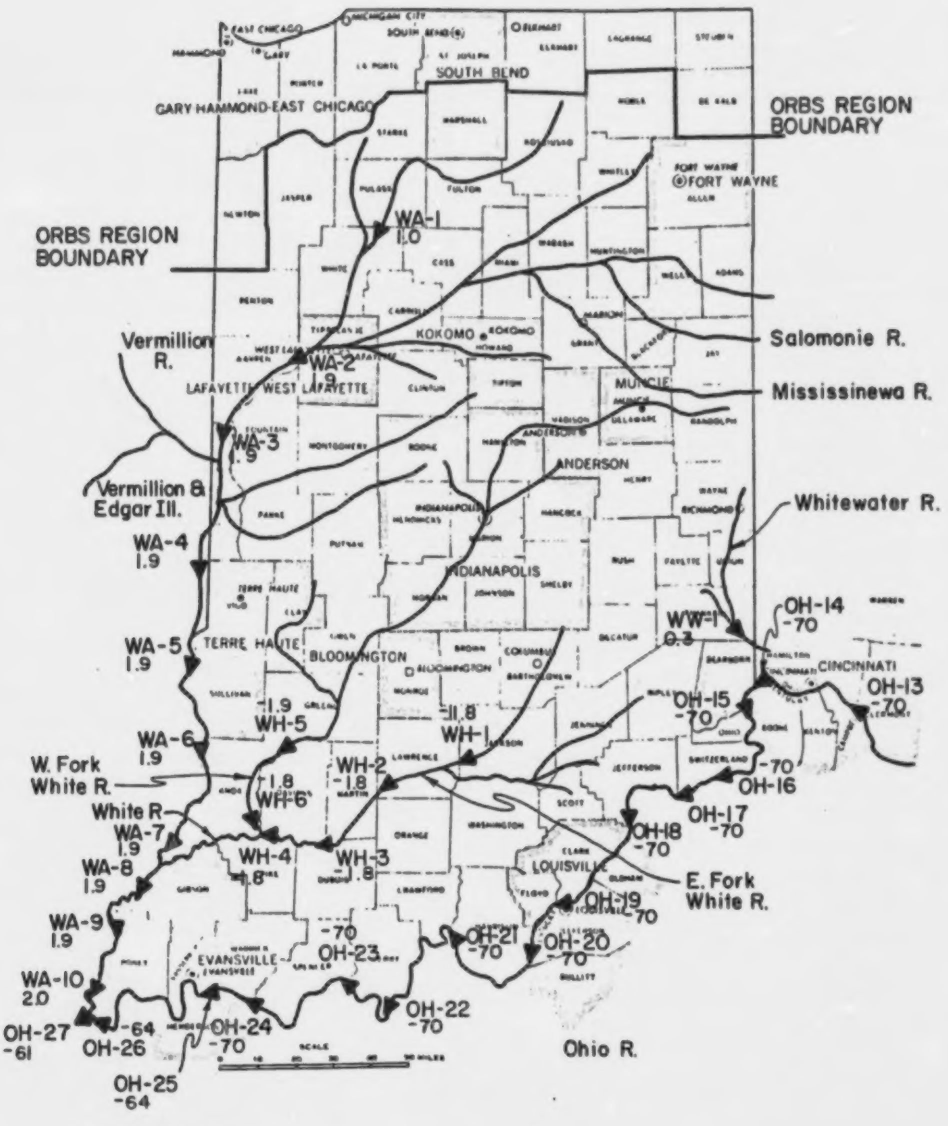
ORBS REGION BOUNDARY
GARY HAMMOND-EAST CHICAGO
SOUTH BEND
FORT WAYNE
ORBS REGION BOUNDARY
WA-1 1.0
Vermillion R.
KOKOMO
WA-2 1.9
LAFAYETTE WEST LAFAYETTE
Salomonie R.
MUNCIE
Mississinewa R.
WA-3 1.9
ANDERSON
Vermillion & Edgar Ill.
Whitewater R.
WA-4 1.9
INDIANAPOLIS
OH-14 -70
WW-1 0.3
WA-5 1.9
TERRE HAUTE
BLOOMINGTON
CINCINNATI
OH-13 -70
OH-15 -70
-1.9 WH-5
-11.8 WH-1
WA-6 1.9
W. Fork White R.
-1.8 WH-6
WH-2 -1.8
-70 OH-16
OH-17 -70
White R.
WA-7 1.9
OH-18 -70
WH-4 -1.8
WH-3 -1.8
LOUISVILLE
E. Fork White R.
WA-8 1.9
OH-19 -70
WA-9 1.9
-70 OH-23
OH-21 -70
OH-20 -70
EVANSVILLE
WA-10 2.0
OH-22 -70
OH-27 -61
-64 OH-26
OH-24 -70
Ohio R.
OH-25 -64
SCALE
MILES

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MAP 3. INDIANA: ALLOWABLE PLANT EQUIVALENTS UNDER 5% CONSUMPTION LIMITS

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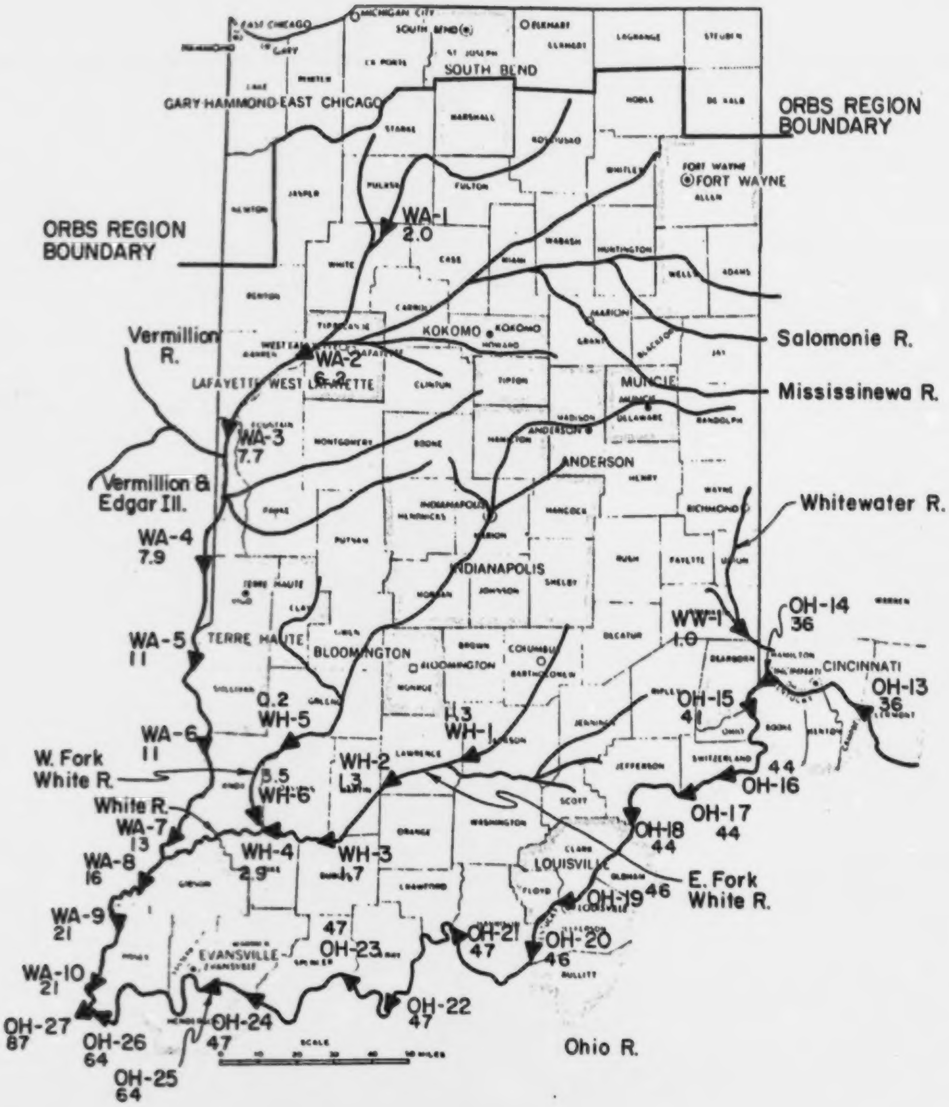
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Salomonie R.
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MUNCIE
Mississinewa R.
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ANDERSON
Vermillion & Edgar Ill.
Whitewater R.
WA-4
7.9
INDIANAPOLIS
OH-14
36
WW-1
1.0
WA-5
11
TERRE HAUTE
BLOOMINGTON
CINCINNATI
OH-13
36
OH-15
41
0.2
WH-5
1.3
WH-1
WA-6
11
W. Fork White R.
3.5
WH-6
WH-2
1.3
44
OH-16
White R.
WA-7
13
OH-17
44
OH-18
44
WH-4
2.9
WH-3
1.7
WA-8
16
LOUISVILLE
E. Fork White R.
OH-19
46
WA-9
21
47
OH-23
OH-21
47
OH-20
46
EVANSVILLE
WA-10
21
OH-22
47
OH-27
87
OH-26
64
OH-24
47
OH-25
64
Ohio R.
SCALE
0 10 20 30 40 50 MILES

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MAP 4. INDIANA: ALLOWABLE PLANT EQUIVALENTS UNDER 10% CONSUMPTION LIMITS

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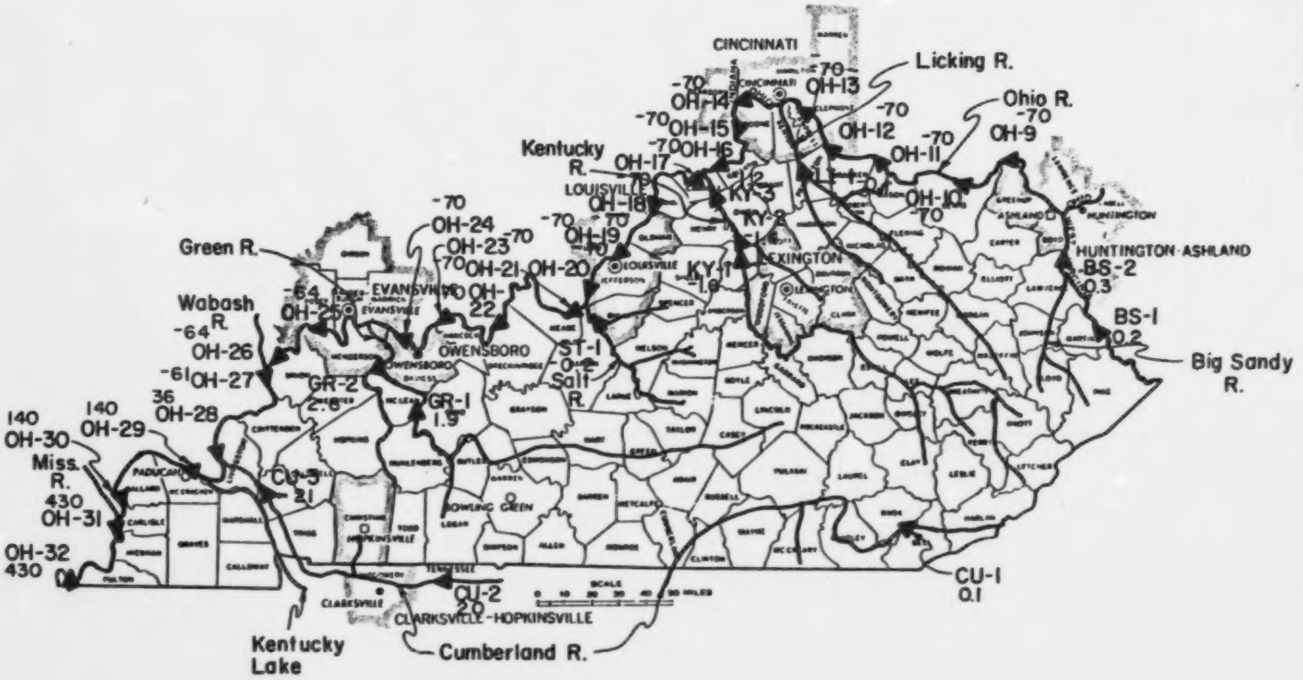
CINCINNATI
Licking R.
Ohio R.
-70
OH-9
-70
OH-10
-70
OH-11
-70
OH-12
-70
OH-13
-70
OH-14
-70
OH-15
-70
OH-16
OH-17
-70
Kentucky R.
LOUISVILLE
OH-18
-70
OH-19
-70
KY-3
1.2
KY-2
-1.6
KY-1
-1.6
LEXINGTON
HUNTINGTON-ASHLAND
BS-2
0.3
BS-1
0.2
Big Sandy R.
CU-1
0.1
OH-20
-70
OH-21
OH-22
70
OH-23
-70
OH-24
-70
ST-1
0.2
Salt R.
OWENSBORO
EVANSVILLE
Green R.
-64
OH-25
Wabash R.
-64
OH-26
-61
OH-27
36
OH-28
GR-2
2.6
GR-1
1.9
140
OH-29
140
OH-30
Miss. R.
430
OH-31
OH-32
430
CU-3
21
CU-2
20
CLARKSVILLE-HOPKINSVILLE
Kentucky Lake
Cumberland R.
SCALE
0 10 20 30 40 50 MILES

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MAP 5. KENTUCKY: ALLOWABLE PLANT EQUIVALENTS UNDER 5% CONSUMPTION LIMITS

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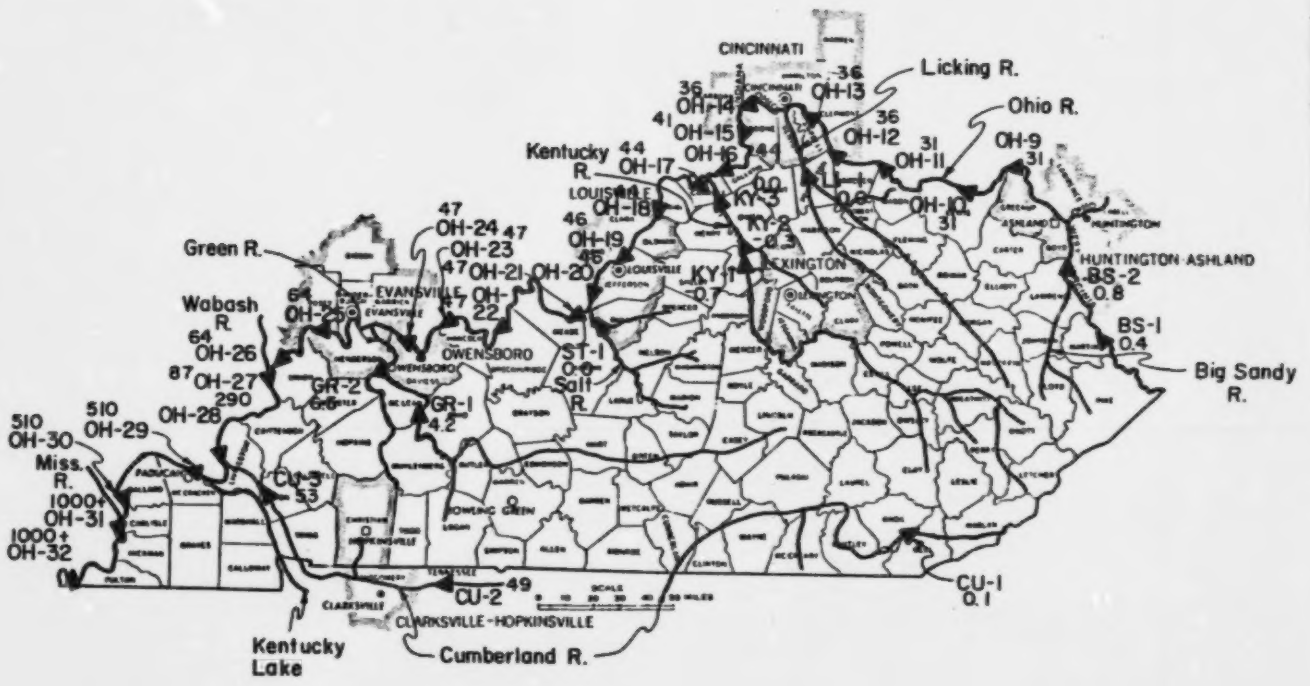
CINCINNATI
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Ohio R.
36 OH-13
36 OH-12
31 OH-11
OH-9 31
OH-10 31
0.0
0.0
36 OH-14
41 OH-15
OH-16 44
Kentucky R.
44 OH-17
LOUISVILLE
OH-18
46 OH-19 46
KY-3
KY-2 0.3
LEXINGTON
KY-1 0.7
HUNTINGTON-ASHLAND
BS-2 0.8
BS-1 0.4
Big Sandy R.
Green R.
47 OH-24
47 OH-23
47 OH-21
OH-20
OH-22 47
EVANSVILLE
OWENSBORO
ST-1 0.0
Salt R.
Wabash R.
64 OH-25
64 OH-26
87 OH-27 290
GR-2 6.6
GR-1 4.2
OH-28
510 OH-29
510 OH-30
Miss. R.
1000+ OH-31
1000+ OH-32
CU-3 53
CU-2 49
CU-1 0.1
BOWLING GREEN
CLARKSVILLE-HOPKINSVILLE
CLARKSVILLE
Cumberland R.
Kentucky Lake
SCALE
0 10 20 30 40 50 MILES

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MAP 6. KENTUCKY: ALLOWABLE PLANT EQUIVALENTS UNDER 10% CONSUMPTION LIMITS

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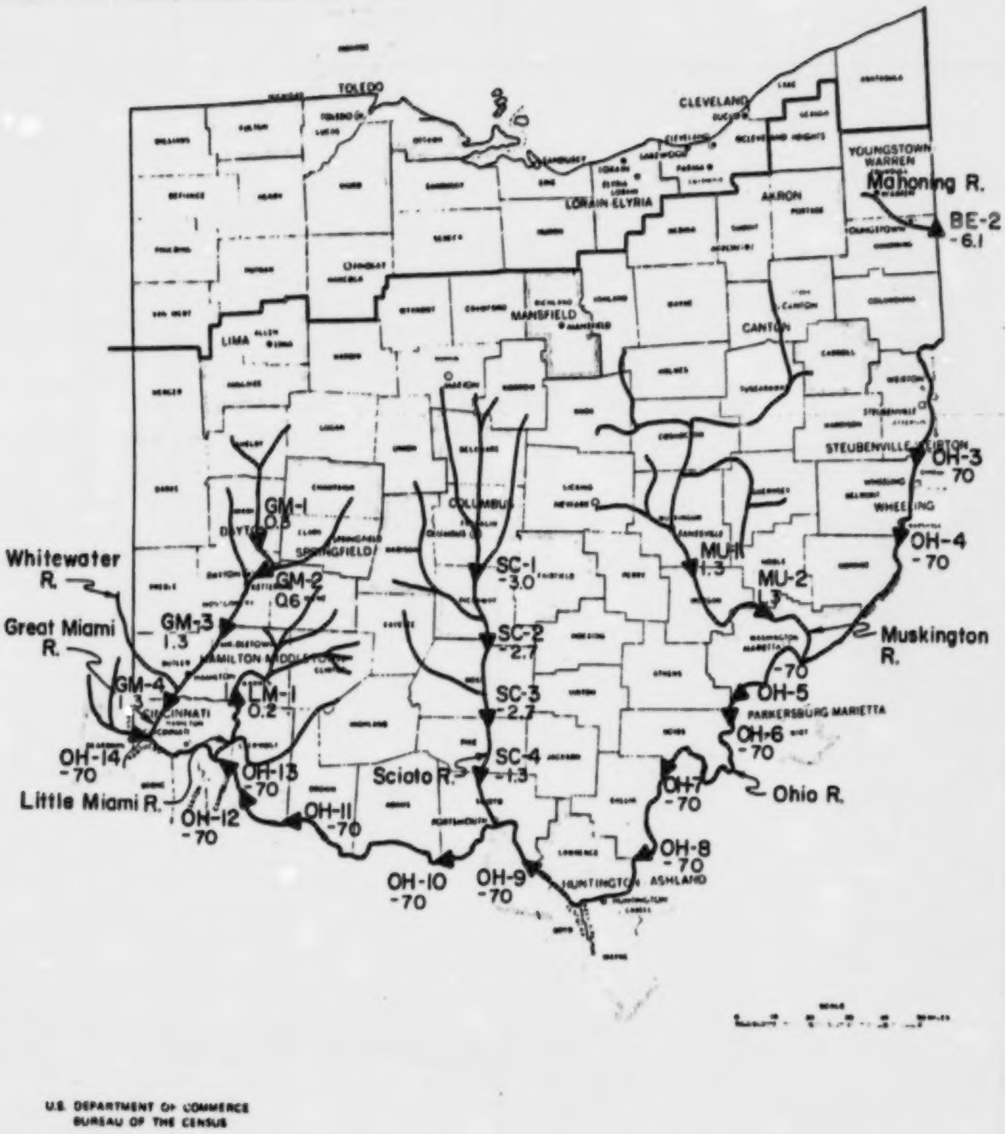
TOLEDO
CLEVELAND
YOUNGSTOWN WARREN
Mahoning R.
BE-2
-6.1
LORAIN ELYRIA
AKRON
MANSFIELD
CANTON
LIMA
STEUBENVILLE WEIRTON
OH-3
-70
WHEELING
OH-4
-70
COLUMBUS
GM-1
0.3
DAYTON
SPRINGFIELD
Whitewater R.
GM-2
0.6
GM-3
1.3
Great Miami R.
HAMILTON MIDDLETOWN
GM-4
1.3
CINCINNATI
LM-1
0.2
SC-1
-3.0
SC-2
-2.7
SC-3
-2.7
SC-4
-1.3
MU-1
1.3
MU-2
1.3
Muskington R.
-70
OH-5
PARKERSBURG MARIETTA
OH-6
-70
Ohio R.
OH-7
-70
OH-8
-70
HUNTINGTON ASHLAND
OH-9
-70
OH-10
-70
OH-11
-70
Scioto R.
OH-12
-70
OH-13
-70
Little Miami R.
OH-14
-70
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MAP 7. OHIO: ALLOWABLE PLANT EQUIVALENTS
UNDER 5% CONSUMPTION LIMITS

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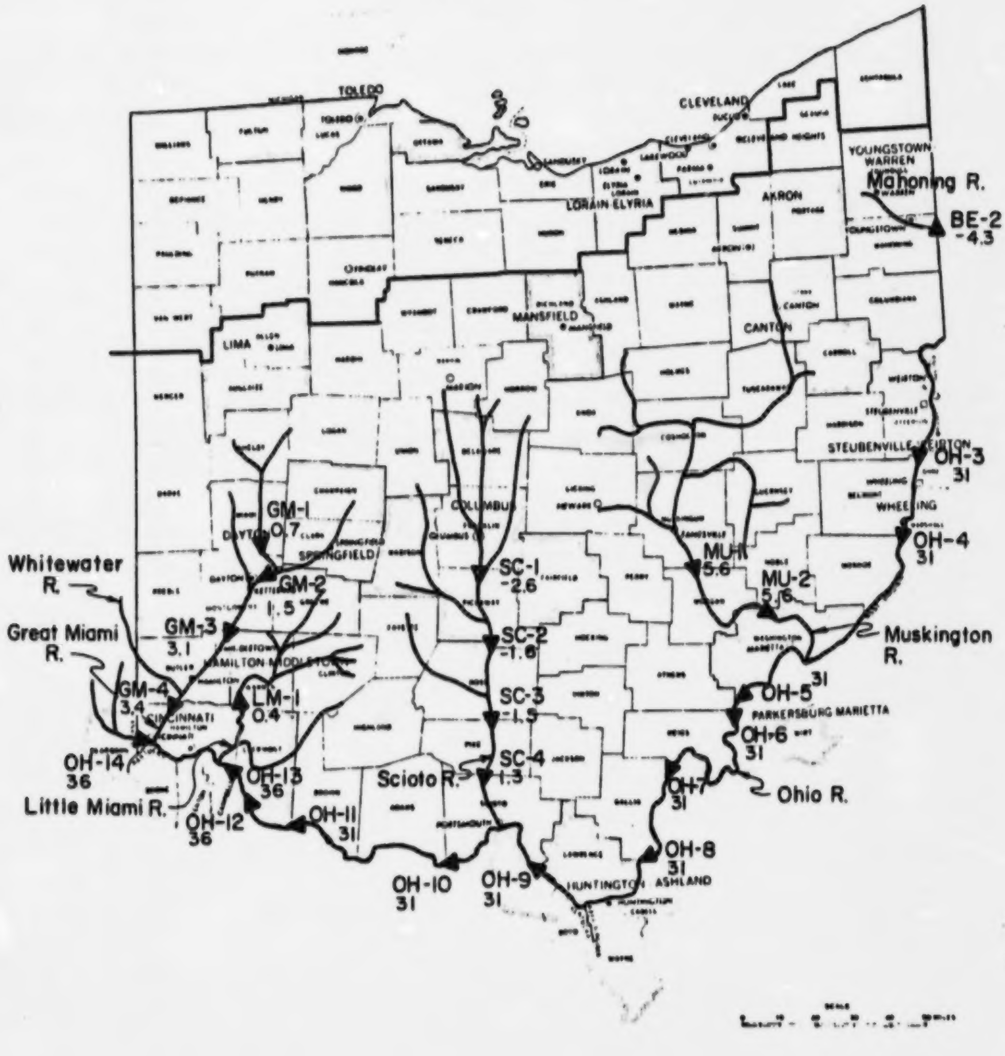
TOLEDO
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LORAIN ELYRIA
YOUNGSTOWN WARREN
Mahoning R.
BE-2
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AKRON
CANTON
MANSFIELD
LIMA
STEUBENVILLE-WEIRTON
OH-3
31
WHEELING
OH-4
31
COLUMBUS
GM-1
0.7
DAYTON
SPRINGFIELD
Whitewater R.
GM-2
1.5
GM-3
3.1
Great Miami R.
HAMILTON-MIDDLETOWN
GM-4
3.4
CINCINNATI
LM-1
0.4
SC-1
-2.6
SC-2
-1.6
SC-3
-1.5
SC-4
-1.3
MU-1
5.6
MU-2
5.6
Muskington R.
OH-5
31
PARKERSBURG MARIETTA
OH-6
31
Ohio R.
OH-7
31
OH-8
31
HUNTINGTON ASHLAND
OH-9
31
OH-10
31
OH-11
31
Scioto R.
OH-12
36
OH-13
36
OH-14
36
Little Miami R.

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MAP 8. OHIO: ALLOWABLE PLANT EQUIVALENTS
UNDER 10% CONSUMPTION LIMITS

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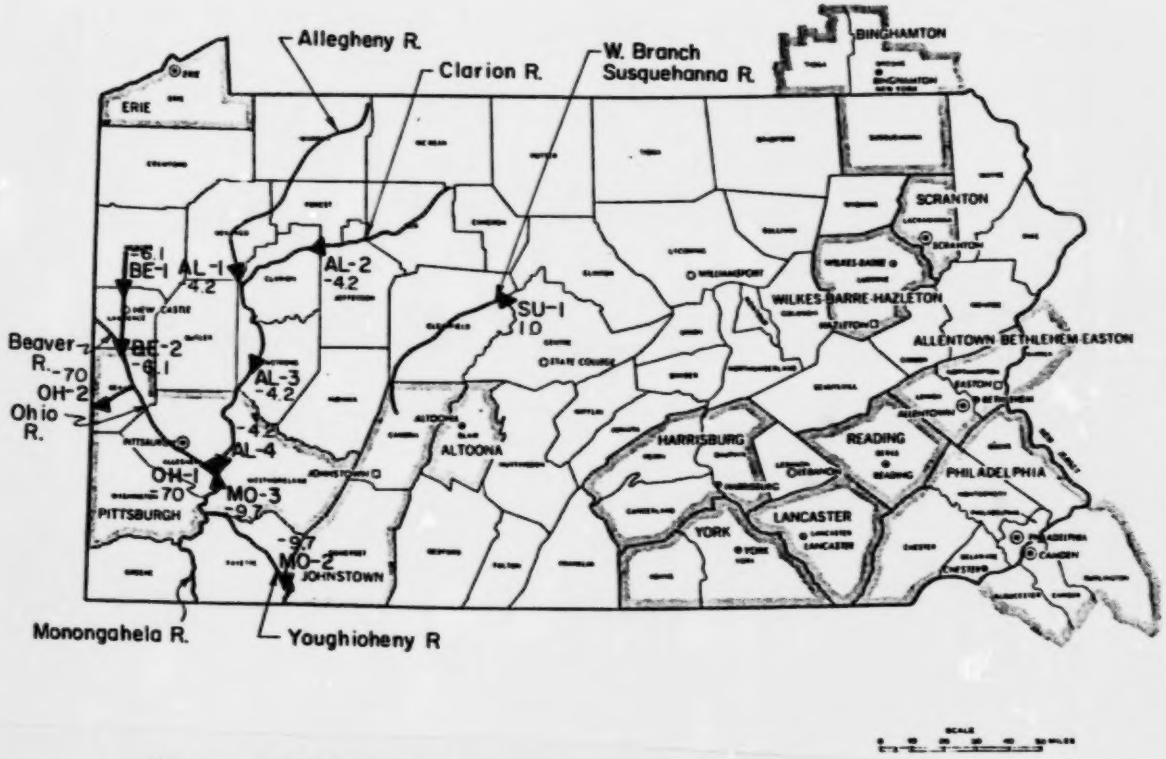
Allegheny R.
Clarion R.
W. Branch Susquehanna R.
BINGHAMTON
ERIE
-6.1
BE-1
AL-1
4.2
AL-2
-4.2
SU-1
1.0
SCRANTON
WILKES-BARRE-HAZLETON
ALLENTOWN-BETHLEHEM-EASTON
Beaver R.
-70
OH-2
BE-2
-6.1
AL-3
-4.2
Ohio R.
-4.2
AL-4
OH-1
-70
MO-3
-9.7
PITTSBURGH
ALTOONA
HARRISBURG
READING
PHILADELPHIA
LANCASTER
YORK
-9.7
MO-2
JOHNSTOWN
Monongahela R.
Youghioheny R

MAP 9. PENNSYLVANIA: ALLOWABLE PLANT EQUIVALENTS UNDER 5% CONSUMPTION LIMITS

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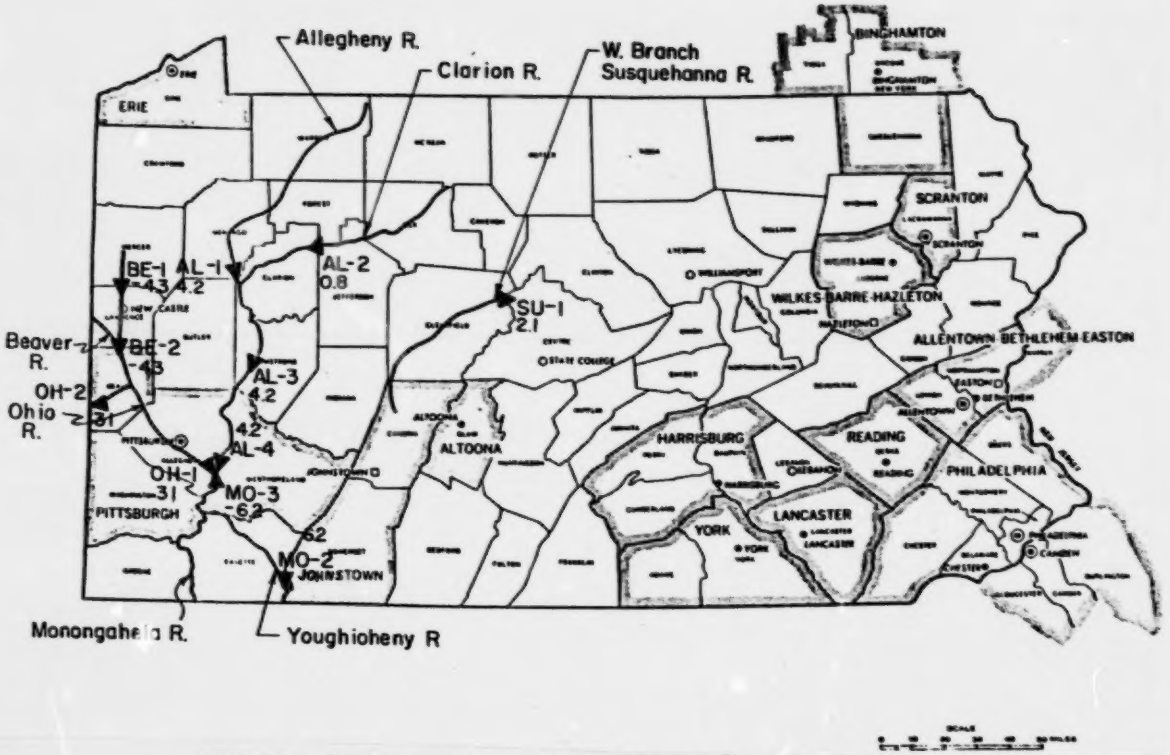
Allegheny R.
Clarion R.
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BINGHAMTON
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BE-1 4.3
AL-1 4.2
AL-2 0.8
SU-1 2.1
STATE COLLEGE
WILLIAMSPORT
SCRANTON
WILKES-BARRE-HAZLETON
ALLENTOWN-BETHLEHEM-EASTON
Beaver R.
BE-2 4.3
AL-3 4.2
OH-2
Ohio R.
31
4.2
AL-4
ALTOONA
HARRISBURG
READING
PHILADELPHIA
OH-1 31
MO-3 6.2
PITTSBURGH
LANCASTER
YORK
6.2
MO-2
JOHNSTOWN
Monongahela R.
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MAP 10. PENNSYLVANIA: ALLOWABLE PLANT EQUIVALENTS UNDER 10% CONSUMPTION LIMITS

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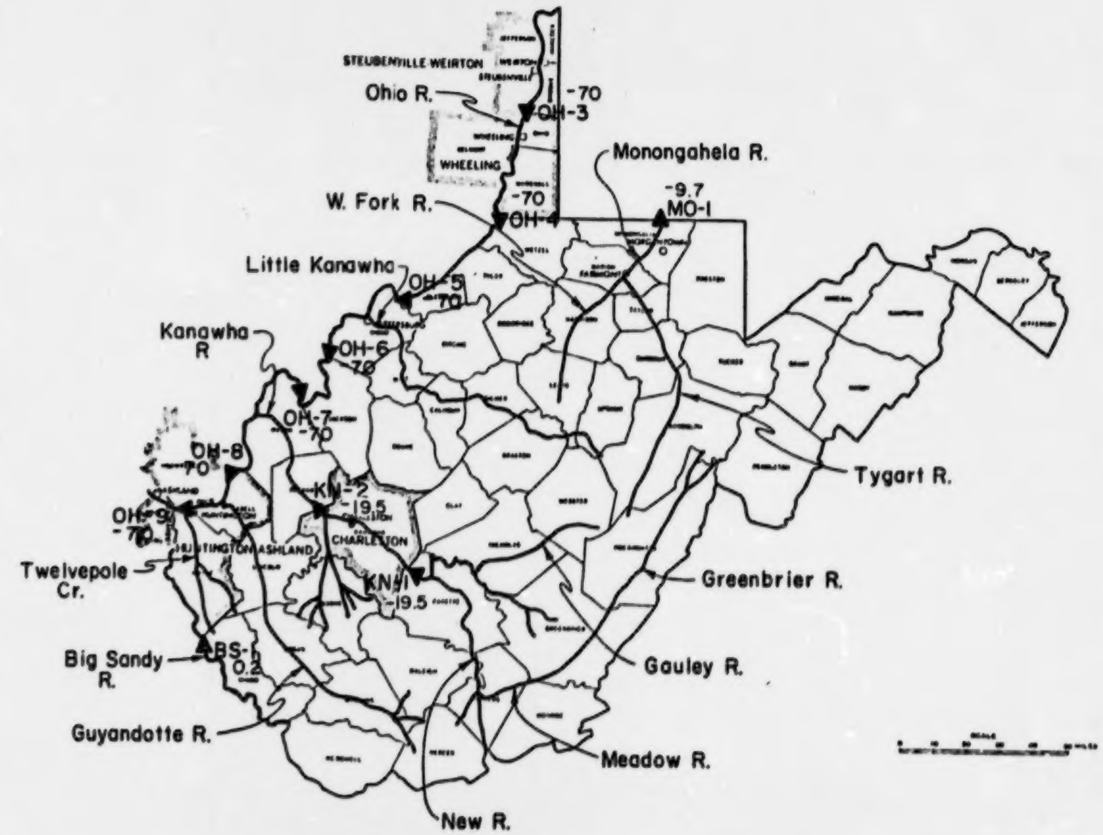
STEUBENVILLE WEIRTON
Ohio R.
-70
OH-3
WHEELING
Monongahela R.
-9.7
MO-1
W. Fork R.
-70
OH-4
Little Kanawha
OH-5
-70
Kanawha R
OH-6
-70
OH-7
-70
OH-8
-70
KN-2
-19.5
CHARLESTON
OH-9
-70
HUNTINGTON ASHLAND
Twelvepole Cr.
KN-1
-19.5
Tygart R.
Greenbrier R.
Gauley R.
Big Sandy R.
BS-1
0.2
Guyandotte R.
Meadow R.
New R.

MAP 11. WEST VIRGINIA: ALLOWABLE PLANT EQUIVALENTS UNDER 5% CONSUMPTION LIMITS

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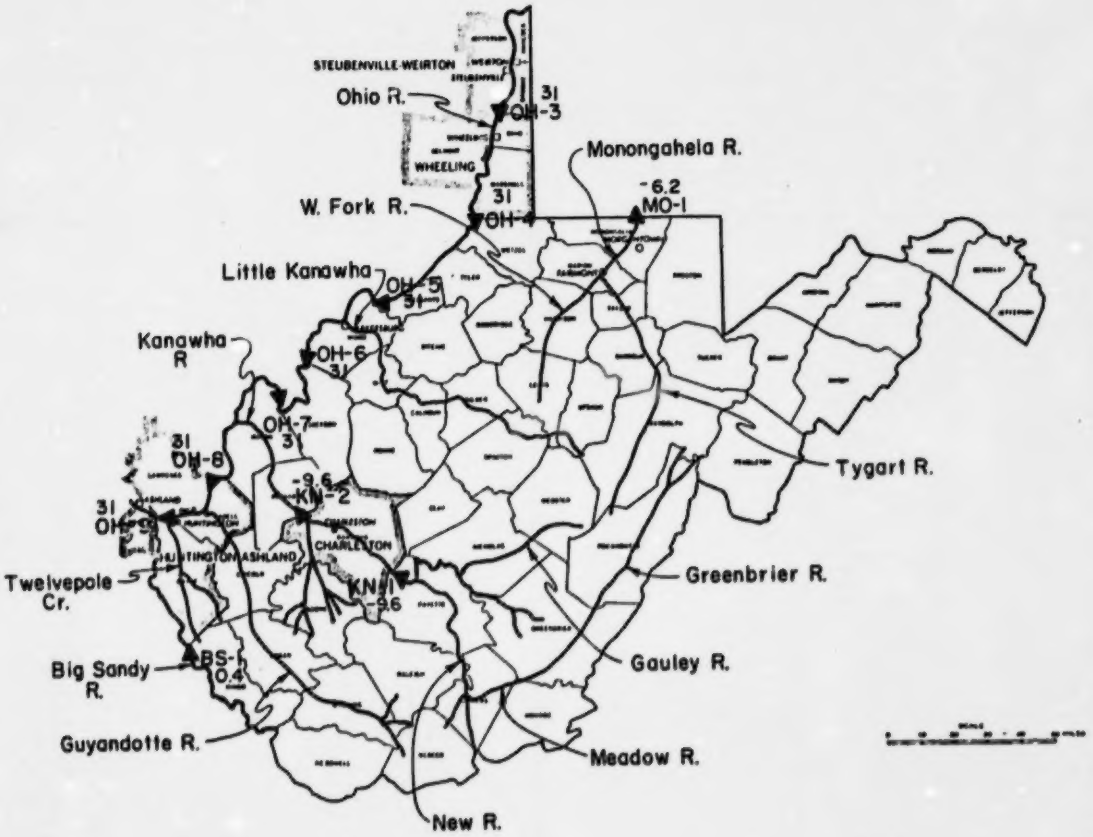
STEUBENVILLE-WEIRTON
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31
OH-3
WHEELING
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OH-4
W. Fork R.
Monongahela R.
-6.2
MO-1
Little Kanawha
OH-5
31
Kanawha R
OH-6
31
OH-7
31
31
OH-8
-9.6
KN-2
CHARLESTON
31
OH-9
HUNTINGTON-ASHLAND
Twelvepole Cr.
KN-1
-9.6
Tygart R.
Greenbrier R.
Gauley R.
Big Sandy R.
BS-1
0.4
Guyandotte R.
Meadow R.
New R.

MAP 12. WEST VIRGINIA: ALLOWABLE PLANT EQUIVALENTS UNDER 10% CONSUMPTION LIMITS

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The tributary rivers in the 5% maps, therefore, do not reflect the negative plant equivalents of the Ohio River. If they did—as might be more logically consistent—the implication would be clearer that essentially no new power plants could be sited anywhere but in the western-most portion of the ORBES Phase II region, without consumption of the Ohio River exceeding the 5% level due the combination of municipal, industrial and power uses.

Basically, the 5% and 10% maps imply that given projected municipal and industrial consumption and currently scheduled power plant additions and removals by the year 2000 most of the Ohio River will have consumption ratios above 5% yet below 10%. Therefore, no new plants could be sited in the eastern portion of the ORBES region, if the 5% limit is to be attained. Note that many plants could be sited, however, if only the 10% level is not to be exceeded.

It should also be pointed out that when the lower set of municipal and industrial consumption factors (.15 and .06, respectively) was used, then the main stem did meet the 5% limit. The 5% limit was not met, however, with much water to spare; for much of the Ohio River under the lower municipal and industrial consumption assumptions, only about six total plants could be sited upstream.

While the maps are drawn as though all the 7-day 10-year low flows are occurring at once, this simplification does not affect the above analysis. The reason is that for this analysis only the low flows in the Ohio River reaches were being discussed; so, even if other rivers were not experiencing low-flow conditions, the "bottleneck" reaches of the Ohio River would still likely experience consumption above 5%, if these reaches were experiencing low-flows. Furthermore, it should be repeated that the figures presented in the maps and discussed here assume the higher set of Ohio River low-flow values, as discussed in section 5.2.7.

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REFERENCES

1. Jansen, Steven D. Electrical Generating Unit Inventory 1976-1986: Ohio River Basin Energy Study Phase II. Energy Resources Center. University of Illinois at Chicago Circle.

2. Personal communication from John E. McSparran, Chief, Division of Comprehensive Resources Programming, Department of Environmental Resources, Harrisburg, Penn., 17120, September 26, 1977.

3. Personal communication from James F. Blakey, District Chief, Water Resources Division, U.S. Geological Survey, Columbus, Ohio, February 2, 1977.

4. U.S. Army Corps of Engineers, Louisville District, and U.S. Department of Agriculture in cooperation with the member agencies of the Wabash River Coordinating Committee. Wabash River Basin Comprehensive Study, App. F., 1971.

5. The Corps of Engineers, U.S. Army Engineer Division, Ohio River, in cooperation with the Department of Agriculture, Department of Commerce, Department of H.E.W., Department of the Interior, FPC, and participating states. Ohio River Basin Comprehensive Survey, App. D., Cincinnati, Ohio, 1967.

6. U.S. Department of the Interior, Federal Water Quality Administration, Great Lakes Region; U.S. Army Engineer Division, North Central; and U.S. Department of Agriculture, for UMRCBS coordinating Committee. Upper Mississippi River Comprehensive Basin Study, App. H., 1970.

7. Personal communication from Richard C. Armstrong, Acting Chief, Planning Division, U.S. Army Corps of Engineers, Cincinnati, Ohio, April 5, 1977.

8. Personal communication from William G. Weist, Jr., Chief of Hydrologic Studies Section, U.S. Geological Survey, Indianapolis, Indiana, October, 1976.

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6. CONSUMPTIVE IMPACTS OF ORBES SCENARIOS

6.1 INTRODUCTION

In this chapter water consumption impacts of ORBES Phase II scenarios are examined. Section 6.1.1 provides a regional overview, and Section 6.2 provides a background for Sections 6.3 through 6.15, which summarize impacts on individual river basins under various scenarios.

6.1.1 Overview of Present and Projected Water Consumption for Power Generation

This section presents an overview of water consumption for power plant cooling in the ORBES region. These estimates may be compared with the projections of municipal and industrial water consumption in Chapter 3 to consider total non-agricultural consumptive demands in the region. Chapter 3 also discusses potential water demands for irrigation.

Based on data in reference 1 on sited generating capacity in the region in 1975 and scheduled plant additions and retirements through the years 1985 and 2000, present and projected cooling water consumption estimates are presented in Table 6.1. The figures in Table 6.1 have been calculated under the following assumptions:

1. All coal generating capacity has been assumed to operate at 50% capacity. Nuclear plants have been assumed to operate at 65% capacity. These load factors have been applied to presently sited electric generating capacity as well as scheduled plant additions and retirements.

2. All sited capacity in 1975 has been assumed for Table 6.1 to use once-through cooling. Scheduled retirements in all cases are also assumed to use once-through cooling.

3. Under the tower assumption category, sited coal and nuclear additions from 1976 through 2000 are all assumed to use wet cooling towers.

4. Under the OTF assumption category, all sited coal and nuclear additions from 1976 through 2000 are assumed to use once-through cooling. This assumption is rather extreme, as not all scheduled additions are at locations for which once-through cooling would be feasible.

5. Consumption rates used to calculate the figures in Table 6.1 are reported in Table 4.5. Table 4.5 also presents water withdrawal coefficients which may be used by interested readers to calculate withdrawal rates. (Of course, water may be reused several times as it moves downstream in a river.)

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TABLE 6.1 PRESENT AND PROJECTED WATER CONSUMPTION FOR POWER PLANT COOLING

	1975	1976-1985		1985	1986-2000		2000
	Sited Capacity	Sited Additions	Removals	Sited Capacity	Sited Additions	Removals	Sited Capacity
Electric Generation Capacity							
Coal (MWe)[1]	70,265	34,843	-4,238	100,870	4,423	-25,220	80,073
Nuclear (MWe)[1]	1,865	8,956	-	10,821	810	-209	11,422
Water Consumption (Tower Assumption)							
Coal (cfs at 50% load)	541.	348	-32.6	856	44.2	-194	706
Nuclear (cfs at 65% load)	23.0	157	0	180	14.2	-2.58	191
Total	564	505	-32.6	1040	58.4	-197	897
Water Consumption (OTF Assumption)[2]							
Coal (cfs at 50% load)	*[3]	268	*[3]	809	34.1	*[3]	649
Nuclear (cfs at 65% load)	*[3]	111	*[3]	134	10.0	*[3]	141
	*[3]	379	*[3]	943	44.1	*[3]	790

1 cfs - 0.646 mgd

[1] From reference 2.

[2] Note that realistically not all sited additions are on sites which could utilize once-through cooling; see text for details.

[3] *Indicates same value as under the tower assumption above.

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The above assumptions differ somewhat from assumptions used in the CORT analysis (see Chapter 5 for a discussion of those assumptions.) Regarding assumptions 2 and 3, it should be recognized that not all sited plants in fact use once-through cooling and not all additions will use towers (some will use cooling ponds, for example). Moreover, not all sited additions are at locations which would permit once-through cooling, even if pollution control regulations were changed to allow more once-through cooling. Assumption 4, then, is an extreme assumption which is useful in determining a lower bound for possible consumption.

Table 6.2 presents projected consumption due to ORBES conjured scenario plants. The data on megawatts of electric generating capacity are from the ORBES scenarios. The water consumption figures are calculated under the following assumptions:

1. Load factors of 50% and 65% are assumed for coal and nuclear plants, respectively.

2. Except under three scenarios (2i, 2a2, 2b1) all conjured plants are assumed in this table to use wet cooling towers and have consumption rates as in Table 4.5. Note that water consumption of plants which may use cooling ponds or other technologies is assumed to be due to cooling towers for Table 6.2.

3. For Scenarios 2i, 2a2, and 2b1, the conjured plant consumption figure is taken from CORT output. This output assumes that only conjured plants on the Illinois, Mississippi, Rock and Ohio Rivers may use once-through cooling, as only these rivers may be large enough.

4. The figures for total cooling water consumption in the year 2000 are calculated based on adding the conjured plant consumption in Table 6.3 to the total figure of 897 cfs calculated for sited capacity in the year 2000 from Table 6.1. To obtain a bound on possible consumption savings if once-through is used for scheduled additions, one might consider the figure of 790 cfs calculated in Table 6.1 under rather extreme alternative assumptions.

Examination of the total conjured and planned plant consumption in Table 6.2 shows that projected consumption due to power generation is largely similar across scenarios. The largest differences are due to differences in generating capacity, with low energy-growth Scenarios 4 and 6 implying just over half of the projected consumption of high energy-growth Scenarios 2b and 7. (Note that Scenario 7 was not analyzed in detail and is not discussed in the following sections.)

The consumption projections presented in Tables 6.1 and 6.2 may be compared with municipal and industrial projections discussed in Chapter 3. Table 3.6, for example, suggests projected municipal and industrial consumption for the ORBES region in the year 2000 to be between 1200 and 2100 million gallons per day (mgd), with 1900 mgd (2940 cfs) being the best estimate. Of this total of 1900 mgd, approximately 1300 mgd is projected to be due to self-supplied industrial use and 600 mgd due to municipal use.

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TABLE 6.2 PROJECTED WATER CONSUMPTION FOR POWER PLANT COOLING FOR ORBES SCENARIOS

	Scenario Number												
	1	2	2i	2a	2a2	2b	2b1	2c	3	4	5	6	7
Incremental Conjured Generating Capacity (MWe at 100% load)													
Coal	61,750	61,750	61,750	81,900	81,900	61,750	61,750	20,800	42,900	22,100	50,700	13,000	91,000
Nuclear	0	0	0	0	0	20,000	20,000	33,000	0	0	0	0	0
Water Consumption for Power Plant Cooling (cfs)													
Coal (at 50% load)	618[4]	618	512[5]	819	680[5]	618	512[5]	208	429	221	507	130	910
Nuclear (at 65% load)	0	0	0[5]	0	0[5]	351	281[5]	579	0	0	0	0	0
Total Conjured Plant Consumption	618	618	512[5]	819	680[5]	969	793[5]	787	429	221	507	130	910
Total Conjured and Planned Plant Consumption in 2000[6]	1520	1520	1410	1720	1580	1870	1690	1680	1330	1120	1400	1030	1810

1 cfs = 0.646 mgd

[4] Includes plants assumed by CORT to use cooling ponds.

[5] Figures from CORT output; only conjured plants on Illinois, Mississippi, Rock and Ohio Rivers are assumed to use once-through cooling for these scenarios.

[6] Adds 897 cfs consumption from sited capacity in the year 2000 from Table 6.2 to total conjured plant consumption. Alternative assumptions—such as widespread adoption of once-through cooling by planned plants—may be considered by using alternative planned consumption figures, e.g., the figure of 790 cfs from Table 6.2.

6.2 BACKGROUND AND ASSUMPTIONS FOR CORT ANALYSIS

Major assumptions of the water availability analysis using the CORT program are explained in Chapter 5. Familiarity with the procedures and issues discussed in that chapter is a prerequisite for understanding the strengths and weaknesses of this analysis. The section on error analysis which follows the discussion of individual scenarios in this chapter is also useful in highlighting key assumptions and limitations.

Except where specifically noted, all ORBES "conjured" power plants are assumed to use evaporative cooling towers. Cooling technologies of planned plants were determined from reference 2, where possible. In examining incremental impacts, planned retirements were first subtracted from planned additions so that impacts of net additions are actually considered. Planned additions and removals from 1971 through those listed in the ORBES Phase II scenarios are included so that all incremental impacts on water consumption are considered. Scenarios 2i, 2a2, and 2b1 are identical to Scenarios 2, 2a, and 2b, respectively, except that they have been evaluated assuming use of once-through cooling by conjured plants on the Illinois, Rock, Mississippi, and Ohio Rivers. A scenario with no conjured plants (the Plant Equivalent Scenario) has also been analyzed.

The discussions in Sections 6.3 through 6.15 are based on the computerized analysis using CORT, and a few issues of presentation should be noted. First, the CORT analysis initially considers tributaries which are grouped by state, and after calculating the tributary consumption, these results are used in the analysis of the Ohio River Main Stem. It should be remembered that upstream consumption on the tributaries is counted against all downstream portions of the basin. Thus consumption on all tributaries--except the Susquehanna River which does not feed into the Ohio Basin--is also counted against the Ohio River Main Stem or Mississippi River.

A minor point of presentation is that the computer files for states sometimes contain counties from neighboring states, because each tributary was analyzed *in toto*. Table 6.3 lists the state files considered and the neighboring states' counties contained in those files. This information may be useful to readers because in the discussions which follow impacts will be discussed by river basins, which may include these neighboring counties.

The tables to follow in Sections 6.3 - 6.14 present the following information: 1) numbers of coal and nuclear conjured plants sited by river basin; 2) ratios of projected power withdrawals and consumption to 7-day 10-year low flow--both the maximum value for the river's reaches and the average value are presented, the power component includes scheduled additions as well as conjured plants; 3) ratios of projected total (municipal, industrial and power) consumption to 7-day 10-year low flow; 4) an arbitrary rating of consumptive impacts based on the average total consumption ratio. In Phase I it was decided to define light impacts by average total consumption ratios below .05, moderate impacts by average ratios between .05 and .25, and heavy impacts by average ratios above .25. (There are, however, no heavy impacts determined in the scenarios discussed here.)

EPA-287 (Cin.)
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TABLE 6.3 COMPUTER FILES FOR STATES AND COUNTIES NOT IN THOSE STATES

File	Counties
Illinois	Jasper county, Indiana in Illinois River Basin
Indiana	Illinois counties on Wabash River
Kentucky	Mingo county, West Virginia in Big Sandy River Basin
Ohio	Franklin and Wayne counties, Indiana in Whitewater River Basin
	Mercer and Lawrence counties, Pennsylvania in Beaver River Basin (only power demands considered; municipal and industrial demands were placed on the Ohio due to data limitations)
Pennsylvania and West Virginia	one file contains counties in both of these states

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(4-76)

6.3 PLANT EQUIVALENT SCENARIO (NO CONJURED PLANTS)

6.3.1 Overview

This scenario consists only of scheduled additions and removals and of projected growth in municipal and industrial consumption. No ORBES conjured plants are included in this scenario which was used to produce the plant equivalent analysis of the preceeding chapter. Understanding the impacts of this scenario, summarized in Table 6.4, provides an initial basis for studying the incremental impacts of conjured plants, because the impacts noted in this scenario continue throughout all the other scenarios.

The greatest percentage consumptive impacts in this scenario occur on reaches of the Scioto, Beaver, Monongahela and Kanawha Rivers. The magnitude of these impacts suggests they be highlighted in this overview section.

Projected consumption on the Scioto River is predominantly due to municipal demands. In reach 1 municipal consumption accounts for 20 cfs out of the 22 cfs total projected consumption, which in turn leads to the high total consumption ratio of .47 for reach 1.

Industry is the cause of most projected consumption on the Beaver River. Incremental industrial consumption in reach 2 accounts for 49 cfs out of 51 cfs total incremental consumption. Most of this industrial consumption is projected to occur in Mahoning county (39 cfs) with the remainder in Trumbull County. The major steel-producing area of Youngstown, Ohio is located in Mahoning County.

It is quite possible that consumption is over-projected for this reach, for three reasons. First, consumption as a percentage of withdrawals may be lower for this type of industry than the average figures used here. Water may be used largely for cooling in a relatively nonconsumptive manner, for example. A second reason for possible over-projection is that heavy industry such as steel production may be growing somewhat more slowly from 1970 to 2000 than the OBERS regional total manufacturing figure. These OBERS projections made in the early 1970's may not reflect the current trend of slower economic growth. (In fact, steel production in Mahoning County may even decrease from 1970 to 2000.) Finally, surface water in the region may be supplied from reservoirs which are regulated to maintain low flow in area rivers.

Consumption on the Monongahela River is largely due to industry. In reach 3, which is projected to have a fairly high ratio of .19, industry accounts for approximately .10, planned additions .05, and municipalities .03. Note that reach 3 of the Monongahela includes a portion of the Pittsburgh area. Growth of industrial consumption projected for this region may be overstated for the first two reasons noted above for the Youngstown area.

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TABLE 6.4 RATIO TABLE FOR PLANT EQUIVALENT SCENARIO

River Basin	Conjured Plants		Power Ratios				Total Ratios		Rating
			Withdrawal		Consumption		Consumption		
	Coal	Nuclear	Max.	Avg.	Max.	Avg.	Max.	Avg.	
Illinois	0	0	1.46	.31	.06	.04	.07	.05	M
Big Muddy	0	0	.00	.00	.00	.00	.12	.12	M
Kaskaskia	0	0	.00	.00	.00	.00	.06	.06	M
Rock	0	0	.00	.00	.00	.00	.00	.00	L
Mississippi	0	0	.05	.02	.01	.00	.02	.01	L
Saline	0	0	.00	.00	.00	.00	.04	.04	L
White	0	0	.04	.02	.03	.01	.09	.05	M
Wabash	0	0	.78	.26	.02	.01	.04	.03	L
Big Sandy	0	0	.00	.00	.00	.00	.01	.00	L
Licking	0	0	.00	.00	.00	.00	.06	.06	M
Salt	0	0	.00	.00	.00	.00	.12	.12	M
Cumberland	0	0	.00	.00	.00	.00	.08	.04	L
Green	0	0	.01	.01	.01	.00	.02	.01	L
Kentucky	0	0	.06	.05	.04	.03	.14	.12	M
Scioto	0	0	.03	.01	.02	.01	.47	.22	M
Muskingum	0	0	.35	.19	.03	.03	.03	.03	L
Whitewater	0	0	.03	.03	.02	.02	.02	.02	L
G. Miami	0	0	.01	.00	.01	.00	.02	.01	L
L. Miami	0	0	.00	.00	.00	.00	.00	.00	L
Beaver	0	0	.00	.00	.00	.00	.22	.11	M
Allegheny	0	0	.08	.03	.05	.02	.08	.03	L
Monongahela	0	0	.08	.05	.05	.03	.19	.08	M
Susquehanna	0	0	.00	.00	.00	.00	.00	.00	L
Kanawha	0	0	.03	.02	.02	.01	.15	.08	M
Ohio	0	0	.12	.06	.04	.03	.08	.06	M

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(4-76)

Industry accounts for most of the projected incremental consumption on the Kanawha River, also. Reach 2 of this river includes the chemical producing center, Charleston, West Virginia. Of a projected total consumption ratio of .15, industry is projected to account for .13. Future industrial consumption may be over-projected for this region, too, as rates of water consumption may be overstated.

Summaries by states of other impacts are discussed below.

6.3.2 Illinois

Consumption due to scheduled additions alone is projected to account for .06 of low-flow of the Illinois River in reaches 4, 5, 6, 8, and 9. Reach 7 is actually the Sangamon River, a tributary to the Illinois River. Note that the demands of the Clinton nuclear power plant in DeWitt county have not been included. This facility is assumed to use stored water which would not affect low-flows. (Scheduled plant additions in Williamson and Jasper counties in Illinois have also been assumed to use stored water.)

The consumption ratio of .12 on the Big Muddy River is due to industrial and municipal demands which have consumption ratios of .10 and .02,respectively.

Municipal and industrial demands on the Mississippi have been estimated for regions adjoining the ORBES area, based on the UMRBCS (3). Scheduled power plant additions for these adjoining regions have not been considered, however. Still, consumption on the Mississippi is projected to be a very small percentage of low flow.

6.3.3 Indiana

Consumption ratios on the White River are projected to be less than .10 for all reaches. Industrial consumption is the largest factor on this river, accounting for a consumption ratio of .05 in reach 5 which has a projected total ratio of .09. Power consumption accounts for roughly .02.

Consumption ratios on the Wabash River are projected to be a low .04, evenly divided between industry and power.

6.3.4 Kentucky

Essentially zero incremental consumption is projected for the Big Sandy River, though a small projected drop in future consumption in Mingo county, West Virginia registers a negative incremental figure for consumption in the summary table. A projected consumption ratio on the Salt River of .12 is a result of industrial and municipal consumption of .07 and .05, respectively. Power consumption is insignificant for most reaches in the state. The Kentucky River may have the largest consumption ratios due to power, with figures which range from .04 to .03.

6.3.5 Ohio, Pennsylvania and West Virginia

Major impacts in these three states were discussed in the overview section (6.3.1).

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EPA-287 (Cin.)
(4-76)

6.3.6 Ohio River Main Stem

Over much of its range the Ohio River is projected to experience consumption ratios between .06 and .08. From reach 10 (where the Scioto River enters) through reach 24 (Daviess county, Kentucky) the total consumption ratios are projected to be .08. Beyond these reaches in either the upstream or downstream direction the consumption ratios are slightly lower, with the total consumption ratio dropping to .04 and below after entry of the Cumberland River. Power demands on the Ohio between reaches 8 and 27 are between .03 and .04, with industrial demands being similar. The lowest reaches of the "Ohio River Main Stem" in the computer analysis are actually Mississippi River reaches adjacent to western Kentucky; and consumption in these reaches is projected to be a small percentage of low-flow.

6.4 SCENARIO 1

6.4.1 Overview

In this scenario ninety-five conjured plants have been sited, all of which are 650 MW coal plants. Seventy-nine of these plants ultimately have an impact upon the Ohio River; one is on the Susquehanna River which is not an Ohio River tributary; and fifteen plants in Ohio have been assumed to use storage (discussed below). At a 50% load factor these sitings imply 30,875 MW of "conjured" power generation.

In this scenario a number of the conjured plants have been dispersed from the major rivers. In the state of Ohio, in particular, plants are located in portions of the state which are not adjacent to major rivers. Plants sited in these counties are assumed by this special study team to use stored water from reservoirs or ponds. Such plants are assumed to have no significant impact on 7-day 10-year low-flows because of discharge regulations. Plants sited in the fifteen Ohio counties in Table 6.5 have not been included in the CORT analysis presented in Table 6.6. Table 6.5 also lists major streams for those counties; all of these streams have low discharge rates.

6.4.2 Illinois

Conjured plant additions in Illinois would have little incremental effect upon the water consumption. Comparison of Table 6.6 with Table 6.4 shows little difference caused by the hypthetical sitings on the Illinois, Rock and Mississippi Rivers.

6.4.3 Indiana

Conjured plants sitings on the White and Wabash Rivers would lead to some minor increases in consumption on those rivers. Consumption along the White River increased by a few percentage points. Reach 1 of the Wabash River is projected to experience a consumption ratio of .10, entirely due to two conjured plants sited in Starke and Pulaski counties. Such plants might conceivably use stored water.

EPA-287 (Cin.)
(4-76)

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TABLE 6.5 OHIO COUNTIES IN WHICH PLANTS ARE ASSUMED TO USE STORAGE AND POTENTIAL SURFACE WATER SOURCES

County	Stream (Basin)
Guernsey	Wills (Muskingum)
Noble[7]	Duck (Ohio)
Knox	Kokosing (Muskingum)
Union	Bokes, Mill (Scioto)
Fayette	Paint (Scioto)
Madison	Darby (Scioto)
Harrison[8]	Conotton (Muskingum)
Perry	Moxahela, Sunday (Muskingum)
Holmes	Killbuck (Muskingum)
Hardin	(Scioto)
Highland	Rock Fork (Scioto)
Morrow	Whetstone, Walnut (Scioto)
Mercer	Beaver (Wabash)
Fairfield	Hocking (Scioto)
Crawford	Olentangy (Scioto)

[7] Has Senacaville Res.
[8] Has Tappan and Glendening Res.

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EPA-287 (Cin.)
(4-76)

TABLE 6.6 RATIO TABLE FOR SCENARIO 1

River Basin[9]	Conjured Plants		Power Ratios				Total Ratios		Rating
			Withdrawal		Consumption		Consumption		
	Coal	Nuclear	Max.	Avg.	Max.	Avg.	Max.	Avg.	
Illinois	3	0	1.50	.31	.07	.05	.08	.06	M
Rock	2	0	.01	.01	.01	.01	.01	.01	L
Mississippi	7	0	.05	.02	.01	.00	.02	.01	L
White	3	0	.09	.05	.06	.04	.14	.08	M
Wabash	9	0	.80	.30	.10	.03	.10	.05	M
Big Sandy	1	0	.37	.26	.25	.18	.24	.18	M
Kentucky	2	0	.15	.14	.11	.09	.20	.18	M
Scioto	2	0	.06	.03	.04	.02	.47	.23	M
Whitewater	1	0	.14	.14	.10	.10	.10	.10	M
G. Miami	1	0	.04	.01	.03	.01	.04	.02	L
L. Miami	1	0	.35	.35	.24	.24	.25	.25	M
Allegheny	11	0	.52	.22	.35	.15	.35	.16	M
Monongahela	3	0	.14	.12	.10	.08	.23	.13	M
Susquehanna	1	0	.07	.07	.05	.05	.05	.05	M
Kanawha	1	0	.04	.02	.03	.02	.15	.08	M
Ohio	79	0	.15	.09	.10	.05	.14	.09	M

[9] All other river basins are as in the Plant Equivalent Scenario.

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

6.4.4 Kentucky

The conjured plant sited in Mingo county, West Virginia is projected to consume roughly 25% of the low-flow of the Big Sandy River in reach 1. Conjured plants on the Kentucky River increase the power consumption by ratio .05 to .08 so that, together with planned additions, the power consumption ratio is projected to attain .11. Together with industrial and municipal use, total consumption ratios range from .16 to .20 for the three reaches.

6.4.5 Ohio

Conjured plants would raise the consumption ratio by .04 in reach 4—the last reach—of the Scioto River, to a total of .11. Upstream reaches have higher consumption ratios due to municipal use.

A conjured plant in Franklin county, Indiana on the Whitewater River is projected to have a consumption ratio of .10. This conjured plant also affects the last reach of the Great Miami River, consuming 5% of its low-flow.

The conjured plant sited in Warren county would consume 24% of the low-flow in the Little Miami River, if this river is the source of water for cooling towers. Storage may be required in this case.

6.4.6 Pennsylvania

Conjured plants sited in Jefferson and Elk counties on reach 2 of the Allegheny River Basin—which actually is the Clarion River—would consume 35% of the flow of this reach. Reaches 3 and 4 projected to experience cumulative power consumption ratios of .10 to .12.

Conjured plants on the Monongahela would contribute to power demands of up to 10% on all three reaches of this river.

A conjured plant on the Susquehanna consumes .05 of the low-flow on that river.

6.4.7 West Virginia

Power consumption ratios on the Kanawha are projected to be only .03 compared with industrial use of .13 in reach 2, the most consumptive region of this river.

As noted under Kentucky the conjured plant in Mingo county, West Virginia may require storage.

6.4.8 Ohio River Main Stem

Consumption ratios along much of the Ohio River are about .10 under Scenario 1. Over most of the river's length, ratios are roughly .02 higher than without any conjured plants.

EPA-287 (Cin.)
(4-76)

6.5 SCENARIO 2 (TOWERS)

In this scenario ninety-five conjured 650 MW coal plants have been sited; ninety-four ultimately affect the main stem, and one is on the Susquehanna River. All conjured plants are assumed to use cooling towers in this analysis. Results are summarized in Table 6.7.

6.5.1 Illinois

Incremental water consumption due to power in the Illinois River Basin is projected to be as much as .08, as compared to almost .06 without conjured plants. Reach 7 which includes the two conjured plants in Menard county may experience .07 more power consumption due to these two plants. Consumption on the Rock and Mississippi Rivers is light.

6.5.2 Indiana

Fewer conjured plants are on the White and Wabash Rivers in this scenario than in scenario 1. Impacts are greatest in Reach 1 of the Wabash River, where two conjured plants in Starke and Pulaski counties will consume .10 of the low-flow.

6.5.3 Kentucky

No conjured plants are sited on tributaries in Kentucky in scenario 2.

6.5.4 Ohio

Power consumption on the Scioto and Muskingam Rivers is relatively light. As noted earlier, the high consumption ratios on the Scioto River are due to high projected municipal demands in Franklin county. Consumption due to conjured power plants on the Beaver River is .08 in both reaches.

6.5.5 Pennsylvania

A conjured plant in Reach 2 of the Allegheny River Basin (Jefferson county, on the Clarion River) is projected to have a consumption ratio of .12. The power consumption ratio on reach 4 is projected to be .09, for a total consumption ratio of .12 in that reach.

Incremental power consumption in reach 3 of the Monongahela is projected to be 10% of low flow. Slightly less than half of this consumption is due to the conjured plants as opposed to planned additions.

6.5.6 West Virginia

No conjured plants are sited on tributaries in West Virginia in Scenario 2.

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EPA-287 (Cin.)
(4-76)

TABLE 6.7 RATIO TABLE FOR SCENARIO 2

River Basin[10]	Conjured Plants		Power Ratios				Total Ratios		Rating
			Withdrawal		Consumption		Consumption		
	Coal	Nuclear	Max.	Avg.	Max.	Avg.	Max.	Avg.	
Illinois	8	0	1.60	.33	.08	.06	.12	.07	M
Rock	2	0	.01	.01	.01	.01	.01	.01	L
Mississippi	12	0	.05	.02	.01	.01	.02	.01	L
Wabash	4	0	.80	.30	.10	.03	.10	.05	M
Scioto	2	0	.06	.03	.04	.02	.47	.23	M
Muskingum	3	0	.40	.24	.07	.06	.07	.06	M
Beaver	3	0	.12	.12	.08	.08	.31	.19	M
Allegheny	7	0	.17	.11	.12	.08	.12	.08	M
Monongahela	3	0	.14	.07	.10	.05	.23	.10	M
Susquehanna	1	0	.07	.07	.05	.05	.05	.05	M
Ohio	94	0	.16	.10	.08	.05	.13	.09	M

[10] All other river basins are as in the Plant Equivalent Scenario

EPA-287 (Cin.)
(4-76)

6.5.7 Ohio River Main Stem

Total consumption ratios between .10 and .11 are projected from reaches 8 to 27 of the Ohio River. Consumption ratios of between .05 and .07 are due to power plants, and conjured scenario plants contribute roughly half of those impacts.

6.6 SCENARIO 2i (ONCE-THROUGH)

An analysis of Scenario 2 was also made assuming once-through cooling use by conjured plants on the Illinois, Rock, Mississippi and Ohio Rivers (see Table 6.8). Planned plants were assumed to use the same technology as in all other scenarios.

The result of using once-through cooling on the Illinois River is a drop in the power consumption ratio by .01 to .02 over most of the reaches. Withdrawal rates on the Illinois in reach 7 due to power are projected to be 640% of low-flow. Therefore, it should not be assumed that the conjured plants in Menard county (which would actually use the Sangamon River) would use once-through because of the relatively low flow of this tributary.

Once-through cooling might be feasible on the Rock River, but would entail high withdrawal rates. Two plants together would withdraw 78% of the Rock River's low-flow. Withdrawal rates on the Mississippi River appear to be relatively high because upstream withdrawals—for example on the Illinois River—are included in the cumulative withdrawal estimate. Environmental impacts of these withdrawals would be largely limited to the Illinois River. Incremental power consumption, however, is projected to be minimal—roughly 1% of flow.

Use of once-through for plants located on the Ohio River in Scenario 2i has little effect on power consumption ratios, decreasing any given ratio by at most .01 in comparison to the ratio obtained assuming towers (Scenario 2). The total consumption ratio over much of the river still ranges between .11 and .10.

6.7 SCENARIO 2a (TOWERS)

In Scenario 2a, 126 conjured 650 MW coal-fired plants are sited. At 50% load this scenario implies 40,950 MW of power generation. This scenario differs from Scenario 2 only for the computer analysis of Ohio, Pennsylvania, and the Main Stem. Results of the CORT analysis are summarized in Table 6.9.

6.7.1 Ohio

Conjured plants sitings on the Scioto River are projected to consume .08 of the flow in reach 4 of that river. Conjured and planned sitings on the Muskingum would lead to power consumption ratio of .08 and .09 in the two reaches of that river. Power consumption ratios on the Beaver River are as much as .11.

6.7.2 Pennsylvania

Power consumption ratios are projected to be near .12 from reaches 2 through 4 of the Allegheny system. The total consumption ratio in reach 4 is projected to be .14.

EPA-287 (Cin.)
(4-76)

TABLE 6.8 RATIO TABLE FOR SCENARIO 21

River Basin[11]	Conjured Plants		Power Ratios				Total Ratios		Rating
			Withdrawal		Consumption		Consumption		
	Coal	Nuclear	Max.	Avg.	Max.	Avg.	Max.	Avg.	
Illinois	8	0	6.40	1.40	.07	.05	.10	.06	M
Rock	2	0	.78	.78	.01	.01	.01	.01	L
Mississippi	12	0	.33	.17	.01	.00	.02	.01	L
Ohio	94	0	2.00	1.30	.08	.05	.13	.09	M

[11] All other river basins are as in Scenario 2.

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 6.9 RATIO TABLE FOR SCENARIO 2a

River Basin[12]	Conjured Plants		Power Ratios				Total Ratios		Rating
			Withdrawal		Consumption		Consumption		
	Coal	Nuclear	Max.	Avg.	Max.	Avg.	Max.	Avg.	
Scioto	4	0	.12	.04	.08	.03	.47	.24	M
Muskingum	5	0	.43	.27	.09	.08	.09	.09	M
Beaver	4	0	.16	.14	.11	.09	.33	.20	M
Allegheny	11	0	.17	.14	.12	.10	.14	.11	M
Monongahela	3	0	.14	.07	.10	.05	.23	.10	M
Susquehanna	1	0	.07	.07	.05	.05	.05	.05	M
Ohio	125	0	.18	.11	.08	.06	.13	.10	M

[12] All other river basins are as in Scenario 2.

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

6.7.3 Ohio River Main Stem

Total consumption ratios over much of the Main Stem between reaches 8 and 27 (where the Wabash enters) are projected to be between .11 and .13. These figures represent an increase of roughly .02 over scenario 2. Consumption due to power in these reaches is roughly .08. Above and below these reaches, consumption is a few percent less.

6.8 SCENARIO 2a2 (ONCE-THROUGH)

Scenario 2a2 differs from Scenario 2a in that once-through cooling is assumed for conjured plants on the Illinois, Rock, Mississippi, and Ohio (Main Stem) Rivers (Table 6.10). Only the Ohio River Main Stem is discussed here since Scenario 2a2 is identical to Scenario 2i for the other rivers. Consumption ratios on the Ohio River between reaches 8 and 27 are roughly .11 to .12, which represents a drop of .01 from the values calculated under Scenario 2a where towers are assumed. Power consuption is roughly .07 over these reaches.

6.9 SCENARIO 2b (TOWERS)

In this scenario ninety-five conjured 650 MW coal-fired plants and twenty conjured 1000 MW nuclear plants were sited. With coal and nuclear plants operating at 50% and 65% load factors, respectively, this scenario implies 43,875 MW of power generation. Only the analyses of Illinois, Pennsylvania and the Ohio River Main Stem differ from Scenario 2; results are summarized in Table 6.11.

6.9.1 Illinois

This scenario differs form Scenario 2 only in that one nuclear plant has been sited in LaSalle county; there is little incremental impact on the water consumption.

6.9.2 Pennsylvania

Because of a number of conjured plants, water consumption ratios due to power range from .10 to .16 on the Allegheny River. Reach 4 experiences the highest power figure, and has a total projected consumption ratio of .18.

Conjured plants on reach 3 of the Monongahela River together with planned additions lead to projected power consumption of .17. A high total consumption figure of .31 is projected for this reach.

6.9.3 Ohio River Main Stem

Total consumption ratios on the Ohio River are projected to attain the level of .09 as early as reach 2 and to stay at least that level until reach 28, where the Cumberland River enters. Between reaches 8 and 27 the consumption ratio is approximately .13. The contribution of power in this region is between .08 and .09.

EPA-287 (Cin.)
(4-76)

TABLE 6.10 RATIO TABLE FOR SCENARIO 2a2

River Basin[13]	Conjured Plants		Power Ratios				Total Ratios		Rating
			Withdrawal		Consumption		Consumption		
	Coal	Nuclear	Max.	Avg.	Max.	Avg.	Max.	Avg.	
Illinois[14]									
Rock[14]									
Mississippi[14]									
Ohio	125	0	2.78	1.86	.07	.06	.12	.09	M

[13] All other river basins are as in Scenario 2.
[14] As in Scenario 2i.

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 6.11 RATIO TABLE FOR SCENARIO 2b

River Basin[15]	Conjured Plants		Power Ratios				Total Ratios		Rating
			Withdrawal		Consumption		Consumption		
	Coal	Nuclear	Max.	Avg.	Max.	Avg.	Max.	Avg.	
Illinois	8	1	1.60	.33	.08	.06	.12	.07	M
Mississippi	12	1	.05	.02	.01	.01	.02	.01	L
Allegheny	7	4	.24	.18	.16	.12	.18	.13	M
Monongahela	3	2	.26	.11	.17	.07	.31	.12	M
Ohio	94	10	.19	.12	.09	.07	.14	.11	M

[15] All other river basins are as in Scenario 2.

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FOR TABLES AND ILLUSTRATIONS

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

6.10 SCENARIO 2b1 (ONCE-THROUGH)

This scenario differs from Scenario 2b, which assumes towers, only for the Illinois River and the Ohio River Main Stem. The impacts on the Illinois are essentially the same as under Scenario 2i. Results are summarized in Table 6.12.

6.10.1 Ohio River Main Stem

With once-through cooling, total consumption ratios on the Ohio River still attains .09 in the second reach and do not drop below that level until reach 28. Between reaches 12 and 27 total consumption ratios are about .12 to .13. Power consumption ratios vary between .07 and .08. Thus, use of once-through cooling would lower consumption on the Ohio by about 1% of the low-flow.

6.11 SCENARIO 2c

In Scenario 2c, thirty-two conjured 650 MW coal plants and thirty-three conjured 1000 MW nuclear plants have been sited. At 50% and 65% load factors for coal and nuclear plants, respectively, this scenario implies 31,850 MW of power generation, or slightly more than the 30,875 MW in scenarios land 2. Results of the CORT analysis are summarized in Table 6.13.

6.11.1 Illinois

Significant consumptive impacts are projected for the Illinois River. Power consumption from reaches 4 through 9 is projected to be at least .11. In reach 7, the Sangamon River tributary reach, the power consumption ratio is projected to be .19 and the total consumption ratio .23. These levels are due to the cooling towers of two conjured nuclear plants in Menard county. These plants might more realistically use a storage system as will be used at the planned Clinton power plants, in DeWitt county. Consumption on the Rock and Mississippi Rivers is projected to be light.

6.11.2 Indiana

One conjured nuclear plant is sited in Starke county and is projected to consume 14% of low-flow in reach 1 of the Wabash River.

6.11.3 Kentucky

No conjured plants are sited on tributaries in Kentucky.

6.11.4 Ohio

Only one conjured plant is on a tributary in Ohio. This plant on the Muskingum River is projected to have little consumptive impact.

6.11.5 Pennsylvania

Consumption ratios for power plants range from .07 to .11 on the Allegheny River. The figure of .11 occurs in Reach 4 and is due half to conjured plants

EPA-287 (Cin.)
(4-76)

TABLE 6.12 RATIO TABLE FOR SCENARIO 2b1

River Basin[16]	Conjured Plants		Power Ratios				Total Ratios		Rating
			Withdrawal		Consumption		Consumption		
	Coal	Nuclear	Max.	Avg.	Max.	Avg.	Max.	Avg.	
Illinois	8	1	6.40	1.70	.08	.06	.10	.07	M
Mississippi	12	1	.40	.19	.01	.01	.02	.01	L
Ohio	94	20	3.30	2.20	.08	.06	.13	.10	M

[16] All other river basins are as in Scenario 2b.

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 6.13 RATIO TABLE FOR SCENARIO 2c

	Conjured Plants		Power Ratios				Total Ratios		Rating
			Withdrawal		Consumption		Consumption		
River Basin[17]	Coal	Nuclear	Max.	Avg.	Max.	Avg.	Max.	Avg.	
Illinois	0	13	1.70	.39	.19	.10	.23	.11	M
Rock	0	2	.04	.04	.03	.03	.03	.03	L
Mississippi	2	19	.07	.03	.03	.01	.03	.02	L
Wabash	2	1	.81	.31	.14	.04	.14	.06	M
Scioto[18]									
Muskingum	1	0	.36	.20	.04	.04	.05	.04	L
Beaver[18]									
Allegheny	1	3	.16	.10	.11	.06	.13	.07	M
Monongahela	3	2	.26	.11	.17	.07	.31	.12	M
Susquehanna[18]									
Ohio	32	33	.16	.09	.07	.05	.11	.08	M

[17] All other river basins as in Scenario 2.
[18] As in the Plant Equivalent Scenario.

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

and half to planned additions. The total consumption ratio in this reach is .13.

The total consumption ratio on the Monongahela River is projected to be .31 in reach 3, of which .17 is due to power plants. Roughly two-thirds of this latter figure is due to conjured plants.

6.11.6 Ohio River Main Stem

From reach 8 to reach 27 the total consumption ratio on the Ohio River is above .09. Over most of this region the total consumption ratio is about .11, and the power contribution is .06.

6.12 SCENARIO 3

This scenario may be viewed as a version of Scenario 2 with twenty-nine fewer coal plants. Scenario 3 sites sixty-six conjured 650 MW coal plants, or roughly two-thirds as many as Scenario 2. Results of the CORT analysis are summarized in Table 6.14.

6-1/2"

6.12.1 Illinois

Consumption ratios on the Illinois River due to power are projected to be .07 at most. The highest total figure in the Illinois River Basin is on reach 7, the Sangamon River tributary reach, and is .09. Reaches 8 and 9 of the Illinois River are projected to have total consumption ratios of .08.

Consumption on the Rock and Mississippi Rivers is projected to be light.

6.12.2 Indiana

The consumption ratio due to power is .10 in reach 1 of the Wabash River because of a total of two conjured coal plants in Starke and Pulaski counties. From reach 2 downstream, power consumption is only about 2% of low-flow.

6.12.3 Kentucky

No conjured plants are sited on tributaries in Kentucky, as in Scenario 2.

6.12.4 Ohio

Conjured plants on the Muskingum consume between 5% and 7% of low-flow, yet the projected total consumption ratios do not exceed .07. Impacts of other conjured plants on tributaries in Ohio are minor.

6.12.5 Pennsylvania

The projected consumption ratio due to power on the Clarion River (reach 2 of the Allegheny River Basin) is .12. Power consumption ratios on reaches 3 and 4 ranges from .07 to .08 with total consumption ratios ranging from .08 to .10.

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 6.14 RATIO TABLE FOR SCENARIO 3

River Basin[19]	Conjured Plants		Power Ratios				Total Ratios		Rating
			Withdrawal		Consumption		Consumption		
	Coal	Nuclear	Max.	Avg.	Max.	Avg.	Max.	Avg.	
Illinois	4	0	1.50	.32	.07	.05	.09	.06	M
Mississippi	8	0	.05	.02	.01	.01	.02	.01	L
Scioto[20]									
Beaver	1	0	.04	.02	.03	.01	.25	.12	M
Allegheny	5	0	.17	.11	.12	.07	.12	.08	M
Ohio	6	6	.15	.08	.06	.04	.10	.08	M

[19] All other river basins as in Scenario 2.

[20] As in the Plant Equivalent Scenario

FOR TABLES AND ILLUSTRATIONS
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EPA-287 (Cin.)
(4-76)

Power consumption ratio on reach 3 of the Monongahela River is projected to be .10, of which just under half is due to conjured plants.

6.12.6 West Virginia

No conjured plants are sited on tributaries in West Virginia, as in scenario 2.

6.12.7 Ohio River Main Stem

From reach 8 to reach 27 projected total consumption ratios on the Ohio River ranges between .09 and .10. The contribution of power is roughly .05 to .06.

6.13 SCENARIO 4

This scenario may be viewed as a further reduced version of Scenario 2 (or Scenario 3). Only thirty-four conjured 650MW coal plants are sited in Scenario 4, or roughly one-third as many as in scenario 2. Results of the consumption analysis are summarized in Table 6.15.

Impacts on the tributaries throughout the ORBES region are minor. No plants are sited in Illinois except on the Mississippi or downstream on the Wabash River. Only one plant is sited in the interior of Ohio, with little impact on the Muskingum River.

In Pennsylvania impacts on the Allegheny are light. The only exception to the light effects on tributaries is reach 3 of the Monongahela, which is projected to have a power consumption ratio of .10 due to planned additions and conjured plants. Slightly more than half of this figure is due to planned plants. Together with industrial and municipal consumption ratios of .10 and .03, this reach is projected to have a total consumption ratio of .23.

6.13.1 Ohio River Main Stem

Between reaches 8 and 27 projected total consumption ratios on the Ohio River ranges from .08 to .09. The contribution of power plants in this region is projected to be .04 to .05. Upstream of these reaches, total consumption ratios are around .06, while downstream total consumption ratios are about .03 or less.

6.14 SCENARIO 5

This scenario is also a reduced version of scenario 2. A total of seventy-eight conjured 650 MW coal-fired plants have been sited. At 50% load these plants would generate 25,350 MW. Indiana, Kentucky, and West Virginia tributaries are unchanged from Scenario 2. Table 6.16 summarizes results of the CORT analysis.

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

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TABLE 6.15 RATIO TABLE FOR SCENARIO 4

	Conjured Plants		Power Ratios				Total Ratios		Rating
			Withdrawal		Consumption		Consumption		
River Basin[21]	Coal	Nuclear	Max.	Avg.	Max.	Avg.	Max.	Avg.	
Mississippi	2	0	.05	.02	.01	.00	.02	.01	L
Wabash	2	0	.78	.26	.03	.01	.05	.03	L
Muskingum	1	0	.36	.20	.04	.04	.05	.04	L
Allegheny	1	0	.08	.03	.06	.02	.08	.03	L
Monongahela[22]									
Ohio	34	0	.14	.07	.05	.04	.09	.07	M

[21] All other river basins are as in the Plant Equivalent Scenario.

[22] As in Scenario 2.

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EPA-287 (Cin.)
(4-76)

TABLE 6.16 RATIO TABLE FOR SCENARIO 5

River Basin[23]	Conjured Plants		Power Ratios				Total Ratios		Rating
			Withdrawal		Consumption		Consumption		
	Coal	Nuclear	Max.	Avg.	Max.	Avg.	Max.	Avg.	
Illinois	5	0	1.50	.32	.07	.05	.09	.06	M
Rock[24]									
Mississippi	9	0	.05	.02	.01	.01	.02	.01	L
Wabash[24]									
Scioto	1	0	.03	.02	.02	.01	.47	.23	M
Muskingum[24]									
Beaver[24]									
Allegheny	5	0	.17	.11	.12	.07	.12	.08	M
Monongahela[24]									
Ohio	78	0	.15	.09	.06	.05	.11	.08	M

[23] All other river basins as in the Plant Equivalent Scenario.
[24] As in Scenario 2.

OF TEXT
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AND ILLUSTRATIONS

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

6.14.1 Illinois

Consumption ratios due to power plants range from .05 to .07 over reaches 3 through 9 of the Illinois River. Projected consumption on the Rock and Mississippi Rivers is light.

6.14.2 Ohio

Consumption ratios on the Muskingum River due to power range from .05 to .07, while power consumption ratios on the Scioto are .02 or less. Power consumption ratios on the Beaver River—due to plants sited in Mercer and Lawrence counties in Pennsylvania—are projected to be .08 in both reaches.

6.14.3 Pennsylvania

The power consumption ratio on the Clarion River—reach 2 of the Allegheny River Basin—is projected to be .12 due to a conjured plant in Jefferson county. Power consumption ratios in reaches 3 and 4 of the Allegheny River are projected to be .07 and .08, with total ratios of .08 and .10. The power consumption ratio on reach 3 of the Monongahela River is again .10 due to planned and conjured plants.

6.14.4 Ohio River Main Stem

Total projected consumption ratios on the Ohio River range between .09 and .11 from reaches 8 through 27. The contribution of power plants to these figures is .05 to .06.

6.15 SCENARIO 6

This scenario may be viewed as a reduced version of Scenario 4, which in turn is a reduced version of Scenario 2. Only twenty conjured 650 MW coal plants are sited in scenario 6; total power generation is 6,500 MW assuming a 50% load factor. Table 6.17 summarizes the consumption analysis.

Consumptive impacts due to conjured power plants are negligible throughout all of the states, as very few conjured plants have been sited on tributaries. The heaviest load on a tributary is from two plants on reach 3 of the Monongahela River, which are projected to consume .08 of the low-flow in that reach.

6.15.1 Ohio River Main Stem

Projected total consumption ratios for the Ohio River range between .06 to .09 from reaches 2 through 27. The contribution of power generation over most of this range is about .04. For comparison, the Plant Equivalent Scenario, which assumed no conjured plants, incremental consumption ratios due to planned power plants alone were projected to be between .03 and .04 over most of these reaches. Thus the impact of the twenty conjured plants of Scenario 6 on the Ohio River is not appreciable.

EPA-287 (Cin.)
(4-76)

TABLE 6.17 RATIO TABLE FOR SCENARIO 6

River Basin[25]	Conjured Plants Coal	 Nuclear	Power Ratios Withdrawal Max.	 Avg.	 Consumption Max.	 Avg.	Total Ratios Consumption Max.	 Avg.	Rating
Mississippi	1	1	.05	.02	.01	.00	.02	.01	L
Wabash	1	0	.78	.26	.03	.01	.05	.03	L
Muskingum	1	0	.36	.20	.04	.04	.05	.04	L
Monongahela	2	0	.08	.03	.05	.02	.08	.03	L
Ohio	20	0	.13	.07	.05	.03	.09	.07	M

[25] All other river basins are as in the Plant Equivalent Scenario.

3/8''
AND ILLUSTRATIONS

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

6.16 SUMMARY

In conclusuon, while regional impacts may occur, power plants are generally not projected to cause severe consumption problems. Local impacts due to industrial consumption seem more likely, though over-projection may be the cause of the severity of these estimates.

Under the highest energy-growth scenario analyzed—Scenario 2b—consumption over much of the Ohio River due to power is projected to be between .08 and .09, with total consumption ratios up to .13 over much of the river. With low growth—as in Scenario 6—conjured plants had little impact on consumption. Total consumption over much of the Ohio River is projected to range between .06 and .09 with planned and conjured power plants contributing roughly .04 to these figures. Note that in Scenario 1, fifteen conjured plants sited in Ohio counties away from major tributaries have been assumed to utilize water storage. These plants were not included in the CORT analysis of consumption. Conjured plants on the Little Miami (Ohio), Clarion (Pennsylvania) and Big Sandy (West Virginia) Rivers are projected to cause significant consumptive impacts. It may be reasonable to assume some use of storage in these cases.

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The use of once-through cooling instead of towers for conjured plants on the Illinois, Rock, Mississippi and Ohio Rivers in Scenarios 2i, 2a2, and 2b1 is projected to have generally little impact on total consumption ratios. Consumption ratios dropped roughly .01 to .02 on the Illinois River under Scenario 2i in comparison to the ratios under Scenario 2. Ratios dropped by at most .01 on the Ohio River in the three scenarios analyzed with once-through cooling. Withdrawal ratios may be more critical to the use of once-through, especially on smaller rivers, such as the Rock River, which experienced withdrawal ratios of .78 due to once-through cooling in Scenario 2c. If no conjured plants are sited, power consumption is projected to be .03 to .04 over much of the Ohio, assuming widespread use of evaporative cooling towers.

6.17 ERROR ANALYSIS

In this section potential sources of error in the water availability analysis are examined. One goal of this examination is to suggest the potential limitations of the quantitative analysis. A second goal is to suggest to users of this study topics which need more investigation and refinement. Certain problems may need general study, such as the amount of evaporative consumption due to once-through cooling. The importance of other assumptions may vary in degree from region to region. Potential sources of errors will be considered as follows:

1. Load factors. Coal-fired plants are assumed by the ORBES Phase II project to operate at 50% of capacity while nuclear plants are assumed to operate at 65% of capacity. One goal of this special study is to examine potentially serious impacts of power development on streamflows. Although 50% and 65% load factors were assumed during low-flow periods, higher generation rates could occur either locally or regionally. For example, low flows may occur during hot, droughty periods accompanying large air conditioning demands. If operating loads were close to 80% for substantial periods of time, incremental water consumption due to power generation might increase by as much as 60% (80/50 = 1.6) in some regions.

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

2. Industrial Water Consumption. There are three major potential sources of error related to industrial use: First, industrial growth may have been over-projected, especially for the types of industry which are water intensive. Second, the consumption rate of .10 used to project consumption (see section 3.3.2) may overstate the percentage consumed in some heavy industrial areas, which use water for cooling and may withdraw large amounts with relatively low consumption rates. These two sources of error may lead to over-projection of water use. They are probably most prevalent for projections near heavy industrial areas, such as the major cities in the ORBES region.

Another potential source of error is that, due to limitations of available data, the computer analysis of Illinois, Kentucky and West Virginia assumed that industrial demands were supplied from surface water in the same proportion as municipal use. (A breakdown of supplies from surface and ground water sources was available for most counties through the basin studies (UMRCBS (3), ORBCS (4)). It would seem, however, that industrial demands may be more likely to be supplied from surface sources than municipal demands. The reasoning is that industry may specifically locate on rivers in order to use their water and that industry may also be able to use lower quality water for cooling while municipal uses may require water of higher quality.

To analyze these potential sources of errors, one scenario (number 2) was analyzed assuming industrial supplies were met exclusively from surface water for a number of counties. Table 6.18 summarizes this analysis; industrial use of surface water was set to 100% in the counties listed.

The effects of these changes were minor. At the very most, consumption on the Ohio River increased by 1%. Similarly, on the Illinois River, the consumption ratio would increase by at most .01 and by this much only for the upper reaches.

3. Industrial and Municipal Consumption Rates. Other items which could affect the consumption analysis are the consumption factors assumed for industries and municipalities. As discussed in Chapter 3, municipal consumption is assumed to be 20% of projected withdrawals. Industrial withdrawals are assumed to remain at roughly the 1970 level, while the rate of consumption is assumed to increase from .10 in proportion to manufacturing earnings. This increasing consumption factor assumption is equivalent—in terms of projecting consumption—to assuming withdrawals increase proportionately with earnings and that the consumption factor remains at .10. This latter procedure (artifically projecting withdrawals) was in fact the projection procedure used by this study, so that industrial withdrawal ratios produced by CORT are misleading. More realistically, incremental industrial withdrawals should be considered zero over the planning horizon of the ORBES project.

It is expected that the estimate of the municipal consumption factor is fairly accurate. The true value of the industrial consumption factor for any region, however, is much less certain, and might be regarded as .10 plus or minus .05. Furthermore, there may be a tendency on the side of over-stating consumption, due to use of projected manufacturing earnings projections which

EPA-287 (Cin.)
(4-76)

TABLE 6.18 COUNTIES CHANGED TO 100% SURFACE WATER FOR INDUSTRIAL USE

Illinois

- **Illinois River**
  - La Salle
  - Putnam
  - Peoria
  - Tazewell
  - Knox
  - Macon
  - Jersey
- **Mississippi River**
  - Madison

West Virginia

- **Kanawha River**
  - Fayette

Ohio River Main Stem

- Hancock, W. Va.
- Brooke, W. Va.
- Marshall, W. Va.
- Wetzel, W. Va.
- Wood, W. Va.
- Jackson, W. Va.
- Mason, W. Va.
- Wayne, W. Va.
- Greenup, Ky.
- Campbell, Ky.
- Dearborn, Ind.
- Carroll, Ky.
- Jefferson, Ind.
- Clark, Ind.
- Meade, Ky.
- Hancock, Ky.
- Daviess, Ky.
- Warrick, Ind.
- Henderson, Ky.
- Pulaski, Il.
- Ballard, Ky.

do not reflect the slower economic growth of the late 1970's. Particularly if the true industrial base rate were closer to .05 than .10, industrial consumption would be much over-projected by our procedure.

Hopefully problems potentially caused by this procedure are minimized for two reasons. First, on the large rivers industrial consumption is generally only a few percent, so if the estimates are off by a percentage point or two, this error is not critical. Second, localities where industrial consumption is suspected to have been over-projected have been noted, specifically in the analysis of section 6.3.1.

4. Cooling Technologies. Estimates of consumption due to power plant cooling technologies are extensively discussed in Chapter 4. There are potential errors in estimates of withdrawals and consumption for the different technologies.

5. Flow-Data. Data on seven-day ten-year low-flows from nearby reaches were used to approximate figures for reaches which did not have flow data available. The approximations are generally simple linear interpolations. Errors in correctly calculating a reach's low-flow value do not appear to be very important, however, because consumption ratios are generally similar from reach to reach.

Another issue is the extent to which present low-flow data reflect contemporary conditions. It is assumed here that flow values represent approximately those conditions occuring in 1970, and that water consumption rates since 1970 can be considered incremental. If low flows in fact occurred many years ago, then when similar meterological conditions again occur the impacts may be more severe, due to higher present levels of consumption.

6. Geographical Issues and Water Sources. A few issues are considered under this heading. First, the computerized analysis included selected counties in the ORBES region—as opposed to all counties. Nearly all counties bordering major tributaries have been included, however, as are all sites for planned and conjured plants. Some judgement has been used in determining which counties should be included in the data base. In general, the goal has been to be as comprehensive as possible. Therefore, some counties which may have slight impact on the tributaries and Main Stem may be included. Some relevant counties may have been omitted, however. The impacts from these two types of errors are likely to be insignificant. Most counties not on tributaries mainly use groundwater, and their incremental demands would be small.

Another type of error would occur if surface water withdrawals and consumption from reservoirs is charged against rivers. There appears to be no way to avoid this source of error without knowledge about individual localities and reservoir operating policies. Without exception, this study has credited surface water consumption to the tributaries. If certain reservoirs operate so as to maintain low-flows, however, then this assumption of incremental consumption from tributaries may overstate future impacts of consumption on low flows.

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

6.17.1 Summary of Error Analysis

Where choices of estimates have been made, a fairly consistent bias in favor of caution may be evident. That is, consumptive impacts may tend to be over-projected rather than under.

The results of the consumption analysis may imply that errors of large magnitude are most likely to occur where problems are currently projected, and these areas may continue to encounter problems even given errors. In low-impact regions, changes of a few percentage points in consumption due to errors would still tend to imply minor overall impacts. Thus, viewed as a regional impact analysis, it is believed the material presented here will serve as a useful first-step. In-depth local analyses are required, of course, when specific sites and tributaries are being considered for actual plants. Power plants may, of course, be sited in regions which this study projects to have high consumption rates; in such a case, however, planners may wish to consider impacts of storage, as well as to investigate alternative cooling technologies.

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

7. ASSESSMENT OF WATER QUALITY IMPACTS

7.1 INTRODUCTION

Potential regional impacts of planned and scenario power plants on water quality were assessed as part of this ORBES special study. Water quality impacts from power plants can be impacts of pollutant loadings or impacts due to water consumption. Pollutant loadings (see Section 7.3) are added to waterways, while water consumption impacts result from the concentration of downstream pollutants because of decreased streamflow.

Ideally, future water quality conditions would be estimated with and without each scenario's power plants to determine their potential impacts. Future estimates of water quality, however, are very difficult to evaluate because of many factors, such as: changing sources of pollutants (e.g., industrial plant openings and closings), changing levels of discharges (e.g., increases, decreases, or changes in industrial activities), changing levels of waste treatment as new regulations are promulgated, and changing conditions in the various waterways (e.g., a shift from carbonaceous to nitrogenous oxygen demanding materials or a change in nonpoint sources of pollution). Thus, this study estimated potential impacts of the various scenarios using current water quality conditions as a reference point. (The method of estimating current water quality conditions is discussed in Section 7.2.) Information developed by state agencies and assembled in most cases by ORBES researchers in the respective states was used for the evaluation; this information, which includes the identification of water quality problem areas, is summarized in Sections 7.2.1 to 7.2.7.

Section 7.4 describes the study methodology, and Section 7.5 provides the regional assessment of the alternative ORBES scenarios. Using current water quality conditions as a reference point, potential incremental deterioration of water quality was estimated by combining load and water consumptive impacts of future power plants. This study is regional in nature; many simplifying assumptions which were necessary are outlined in following sections.

7.2 ESTIMATED BACKGROUND WATER QUALITY CONDITIONS FOR SCENARIO ASSESSMENTS

Current water quality conditions were evaluated and are discussed below by state. The Ohio River is discussed separately in Section 7.2.7.

Three issues related to assessing current water quality conditions are:

1) Since water quality conditions change historically, current water quality should be estimated using current data;

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

2) Since water quality is stochastic, a significant amount of data is required to obtain a representative estimate of current conditions;

3) Since water quality is variable seasonally, it is often desirable to focus on worse-case conditions.

For each state, the extent of the data was highly variable and presented many limitations. The following method was used in general:

1) Water quality data from 1973 to 1977 were analyzed. If these data were sparse for a given reach, then data from an additional year or two were added. If the data were still insufficient, then in some cases data from adjacent reaches were used. In some cases, current water quality conditions could not be described.

2) Average concentrations during low-flow conditions were summarized since those are the conditions most likely affected by power plants. The effects of water consumption are generally significant only during low-flow periods, and the incremental impacts on ambient concentrations of pollutants discharged from plants are greatest during those periods.

In general, averages of monthly data from August through November were used. These concentrations were used as indicators of current water quality conditions and as reference points for calculations of incremental concentrations due to future power plants. (The methodology used in this study is described in Section 7.4.)

Table 7.1 summarizes estimated current water quality for twenty rivers in the ORBES region. Parameter values are given in milligrams/liter (mg/l). Estimates are included for twenty constituents: total dissolved solids (TDS), total suspended solids (TSS), sulfate (SO_4), ammonia (NH_3), arsenic (As), barium (Ba), cadmium (Cd), chloride (Cl), chromium (Cr), phosphorus (P), selenium (Se), silver (Ag), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), mercury (Hg), nickel (Ni), zinc (Zn), and boron (B).

The following subsections describe exceptions to the general procedure outlined above and list water quality problem areas in each state.

7.2.1 Illinois

Using 1969-1974 data from the U.S. Geological Survey (1), the general procedure described in Section 7.2 was used to estimate current water quality conditions for the following rivers: Illinois, Big Muddy, Kaskaskia, and Mississippi. For some locations along all rivers, a comparison of estimated current water quality conditions with state water quality standards shows violations of standards for manganese and iron. Although the TDS concentrations are generally lower than the standard in all rivers, the TDS concentrations in the Illinois, Kaskaskia, and Big Muddy Rivers are approximately 80% to 90% of the standard. For the Illinois River, violations of the Hg state standard occur in approximately 40% of the reaches.

EPA-287 (Cin.)
(4-76)

TABLE 7.1 SUMMARY OF CURRENT WATER QUALITY CONDITIONS - ILLINOIS

River	Reach	Constituent (mg/l) TDS	TSS	SO_4	NH_3	As	Ba	Cd	Cl	Cr	P	Se	Ag	Cu	Fe	Pb	Mn	Hg	Ni	Zn	B
Illinois	1	385	-	96	.15	0	0	0	19	0	.1	0	0	.08	.5	.025	.14	0	0	0	.15
	2	460	-	101	1.33	.002	.03	0	62	0	.84	0	0	.012	.42	.015	.08	.00008	0	0	.37
	3	460	-	101	1.33	.002	.03	0	62	0	.84	0	0	.012	.42	.015	.08	.00008	0	0	.37
	4	444	-	95	.26	0	.05	0	60	0	.58	0	0	.128	.12	.104	.15	0	0	.038	.42
	5	421	-	64	.12	.002	.08	0	41	0	.51	0	0	.002	3.2	.005	.23	.00008	0	0	.48
	6	421	-	64	.12	.002	.08	0	41	0	.51	0	0	.002	3.2	.005	.23	.00008	0	0	.48
	7	402	-	55	.06	0	.1	0	28	0	.48	0	0	.002	2.0	.007	.26	.00002	0	0	.28
	8	422	-	82	.11	0	.1	0	42	0	.49	0	0	.036	2.4	.034	.18	.00004	0	0	.35
	9	400	-	88	.09	.001	.1	0	49	0	.41	0	0	.002	1.6	.002	.14	0	.025	0	.32
Big Muddy	1	484	-	210	.18	.001	.1	0	36	0	1.32	0	0	.01	3.0	.01	.73	0	0	0	.1
Kaskaskia	1	400	-	39	.55	-	-	-	20	-	.58	-	-	.01	3.4	<.05	.95	- -	<.05	.015	.1
Rock	1	Not available																			
Mississippi	1	256	-	73	.19	.0004	.07	0	15	0	.22	0	0	0	.3	.013	.12	.00003	0	0	.17
	2	256	-	73	.19	.0004	.07	0	15	0	.22	0	0	0	.3	.013	.12	.00003	0	0	.17
	3	256	-	73	.19	.0004	.07	0	15	0	.22	0	0	0	.3	.013	.12	.00003	0	0	.17
	4	256	-	73	.19	.0004	.07	0	15	0	.22	0	0	0	.3	.013	.12	.00003	0	0	.17
	5	310	-	62	.11	.0005	0	0	22	0	.3	0	0	.01	3.1	0	.12	0	0	0	.10
	6	295	-	48	.10	.004	0	0	21	0	.22	0	0	.55	2.0	.01	.15	0	0	0	.10
	7	337	-	112	.12	.0008	.06	0	22	0	.31	0	0	.08	1.4	.001	.16	0	0	.025	.16

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EPA-287 (Cin.)
(4-76)

TABLE 7.1 SUMMARY OF CURRENT WATER QUALITY CONDITIONS - INDIANA

		Constituent (mg/l)																			
River	Reach	TDS	TSS	SO_4	NH_3	As	Ba	Cd	Cl	Cr	P	Se	Ag	Cu	Fe	Pb	Mn	Hg	Ni	Zn	B
White	1	548	37	44	.23	<.01	-	<.01	22	<.01	.47	-	-	.16	.41	.03	.41	.0009	.12	.08	-
	2	422	27	36	1.13	<.01	-	<.01	21	<.01	.24	-	-	.02	.57	.03	.09	.00025	<.02	.068	-
	3	422	27	42	.24	<.01	-	<.01	19	<.01	.18	-	-	.02	.57	.03	.09	.00025	<.02	.068	-
	4	503	86	68	.15	<.01	-	<.01	23	<.01	.53	-	-	.02	1.2	.03	.09	.00025	<.02	<.02	-
	5	503	86	68	.15	<.01	-	<.01	23	<.01	.53	-	-	.02	1.2	.03	.09	.00025	<.02	<.02	-
	6	503	86	68	.15	<.01	-	<.01	23	<.01	.53	-	-	.02	1.2	.03	.09	.00025	<.02	<.02	-
Wabash	1	609	42	95	.48	-	-	-	33	-	2.0	-	-	-	-	-	-	-	-	-	-
	2	609	42	95	.48	-	-	-	33	-	2.0	-	-	-	-	-	-	-	-	-	-
	3	609	42	59	.48	-	-	-	33	-	.19	-	-	-	-	-	-	-	<.08	-	-
	4	566	98	71	.24	-	-	-	23	-	.57	-	-	-	-	-	-	-	<.08	.14	-
	5	566	98	71	.24	-	-	-	23	-	.57	-	-	-	-	-	-	-	<.08	.14	-
	6	566	98	71	.24	-	-	-	23	-	.57	-	-	-	-	-	-	-	<.08	.14	-
	7	580	49	72	.15	-	-	<.01	29	-	.27	-	-	<.08	2.32	.04	-	.0013	<.02	-	-
	8	580	49	72	.15	-	-	<.01	29	-	.27	-	-	<.08	2.32	.04	-	.0013	<.02	-	-
	9	580	49	72	.15	-	-	<.01	29	-	.27	-	-	<.08	2.32	.04	-	.0013	<.02	-	-
	10	580	49	72	.15	-	-	<.01	29	-	.27	-	-	<.08	2.32	.04	-	.0013	<.02	-	-

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(4-76)

TABLE 7.1 SUMMARY OF CURRENT WATER QUALITY CONDITIONS - KENTUCKY, WEST VIRGINIA, PENNSYLVANIA

		Constituent (mg/l)																		
River	Reach	TDS	TSS	SO_4	NH_3	As	Ba	Cd	Cl	Cr	P	Se	Ag	Cu	Fe	Pb	Mn	Hg	Ni	Zn	B
Green	1	218	72	69	.12	.01	.3	<.005	13	.03	.25	<.005	<.03	<.03	3.72	.075	1.7	.0003	.031	.11	-
	2	218	72	69	.12	.01	.3	<.005	13	.03	.25	<.005	<.03	<.03	3.72	.075	1.7	.0003	.031	.11	-
Kentucky		Not available																			
Big Sandy	1	180	137	91	.18	.009	.16	.006	7.8	.034	.3	.01	.002	.112	21.5	.06	.98	.0005	.05	.27	-
	2	180	137	91	.18	.009	.16	.006	7.8	.034	.3	.01	.002	.112	21.5	.06	.98	.0005	.05	.27	-
Allegheny	1	742	-	36	.19	.06	-	-	16	-	.13	-	-	.5	.43	.06	.16	.0008	.05	.05	-
	2	742	-	36	.19	.06	-	-	16	-	.13	-	-	.5	.43	.06	.16	.0008	.05	.05	-
	3	143	-	67	.31	.02	-	-	16	-	.14	-	-	.5	1.09	.1	.66	.0005	.05	.08	-
	4	162	43	74	.27	.001	.1	.005	12	.038	.10	<.01	.001	.024	3.89	.06	1.04	.0011	.04	.18	-
Monongahela	1	174	-	107	.43	-	-	-	18	-	.19	-	-	.01	1.4	.04	.36	-	.04	.26	-
	2	247	-	123	.57	-	-	-	16	-	.83	-	-	.015	1.12	.05	.27	-	.05	.12	-
	3	226	32	123	.53	.002	.1	.007	16	.02	.13	<.01	.001	.035	3.05	.05	.54	.0005	.03	.15	
Susquehanna	1	Not available																			
Kanawha	1	170	-	31	-	<.002	-	-	-	-	-	-	-	-	.64	<.05	.13	.0003	-	.028	-
	2	114	37	43	.41	.0042	.1	.01	17	.016	.24	<.01	<.001	.036	2.5	.33	.24	<.0005	.03	.24	-

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EPA-287 (Cin.)
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TABLE 7.1 SUMMARY OF CURRENT WATER QUALITY CONDITIONS - OHIO

		Constituent (mg/1)																			
River	Reach	TDS	TSS	SO_4	NH_3	AS	Ba	Cd	Cl	Cr	P	Se	Ag	Cu	Fe	Pb	Mn	Hg	Ni	Zn	B
Scioto	1	378	34	80	.24	<.01	<.2	.01	39.7	<.03	.23	.01	.03	<.03	2.16	<.01	.07	.0013	-	.03	-
	2	442	41	107	1.32	<.01	<.2	<.01	43.8	<.03	.68	.03	<.03	<.03	1.62	.017	.095	<.0005	-	.05	-
	3	418	52	102	.63	<.01	<.2	<.01	36	<.03	.51	<.01	<.03	<.03	.96	.012	.1	<.0005	-	.05	-
	4	401	104	86	.44	.005	.2	.007	22	.06	.75	<.01	.002	.04	12.0	.1	1.4	<.0005	.07	.15	-
Muskingum	1	492	69	134	.19	<.01	<.2	.01	88	<.03	.13	<.01	<.03	.04	4.21	.018	.59	<.0005	-	.07	-
	2	476	83	154	.33	.002	.1	.013	33	.044	.18	<.01	.001	.032	6.5	.6	.95	.0016	.04	.11	-
Whitewater	1	324	73	-	.13	-	-	-	-	-	.09	-	-	-	-	-	-	-	-	-	-
G. Miami	1	413	40	69	.67	<.01	<.2	<.01	30	<.03	.55	<.01	<.03	.06	1.96	.017	.075	.001	-	.04	-
	2	409	-	-	.32	-	-	-	15	-	.40	-	-	-	-	-	-	-	-	-	-
	3	435	106	62	.51	<.01	.4	<.01	49	.09	.47	<.01	<.03	.06	7.22	.077	.45	<.0005	-	.245	-
	4	313	97	75	.63	.002	.2	.012	37	.04	.58	.01	.006	.086	20.5	.13	.4	<.0005	.03	.51	-
L. Miami	1	387	129	51	.37	.002	.1	.017	41	.02	.69	<.01	.001	.18	11.5	.2	.54	<.0005	.02	.11	-
Beaver	1	317	30	93	2.54	<.01	<.2	<.01	54	.05	.46	<.01	<.03	.06	3.44	.024	.31	<.0005	-	.218	-
	2	233	23	88	.91	.002	.1	.006	30	.03	.23	<.01	.002	.112	5.5	.05	.6	.0005	.04	.17	-

TABLE 7.1 SUMMARY OF CURRENT WATER QUALITY CONDITIONS - OHIO RIVER

								Constituent (mg/l)													
Reach	TDS	TSS	SO_4	NH_3	As	Ba	Cd	Cl	Cr	P	Se	Ag	Cu	Fe	Pb	Mn	Hg	Ni	Zn	B
1	302	48	92	.51	.005	.11	.007	20	.031	.15	<.01	.001	.32	7.5	.06	.8	.0007	.07	.24	-
2	302	48	92	.51	.005	.11	.007	20	.031	.15	<.01	.001	.32	7.5	.06	.8	.0007	.07	.24	-
3	312	42	105	.53	.017	.1	.019	20	.14	.16	<.01	.001	.32	7.5	.5	.64	.0024	.07	.23	-
4	312	39	107	.53	.017	.33	.019	18	.14	.16	<.01	.001	.02	12	.5	1.3	.0024	.035	.24	-
5	312	27	119	.47	.005	.1	.005	20	.02	.13	<.01	.001	.13	7.7	.89	1.7	.0009	.11	.32	-
6	400	41	115	.38	.007	.11	.004	23	.03	.21	<.01	.001	.047	9.5	.41	.85	.0008	.02	.19	-
7	400	59	115	.46	.007	.11	.007	23	.03	.16	<.01	.001	.062	9.5	.41	.85	.0008	.03	.19	-
8	344	53	80	.5	.004	.11	.03	16	.02	.15	<.01	.001	.058	12	.09	1.26	.0011	.02	.23	-
9	331	86	81	.44	.002	.12	.044	21	.044	.32	<.01	.001	.136	16	.15	2.8	<.0005	.05	.4	-
10	331	70	77	.46	.002	.1	.007	11	.02	.31	<.01	.001	.036	7.5	.055	3.8	.0005	.03	.15	-
11	331	70	77	.46	.002	.1	.007	11	.02	.31	<.01	.001	.036	7.5	.055	3.8	.0005	.03	.15	-
12	331	55	79	.44	.007	.12	.008	19	.028	.28	<.01	.001	.4	9	.18	1.16	<.0005	.075	.18	-
13	331	96	79	.44	.007	.12	.008	19	.036	.32	<.01	.002	.4	20.5	.18	1.46	.0007	.075	.26	-
14	320	96	83	.34	.01	.11	.007	19	.036	.32	<.01	.001	.126	20.5	.07	1.46	.0007	.04	.26	-
15	314	62	83	.34	.01	.11	.004	18	.02	.23	<.01	.001	.126	7.3	.05	.56	<.0005	.03	.13	-
16	325	45	76	.35	.002	.1	.007	23	.05	.2	<.01	.003	.28	9.2	.085	.4	<.0005	.02	.11	-

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EPA-287 (Cin.)
(4-76)

TABLE 7.1 OHIO RIVER (CONTINUED)

	Constituent (mg/l)																			
Reach	TDS	TSS	SO_4	NH_3	As	Ba	Cd	Cl	Cr	P	Se	Ag	Cu	Fe	Pb	Mn	Hg	Ni	Zn	B
17	325	45	76	.35	.002	.1	.007	23	.05	.2	<.01	.003	.28	9.2	.085	.4	<.0005	.02	.11	-
18	325	45	76	.35	.002	.1	.007	23	.05	.2	<.01	.003	.28	9.3	.085	.4	<.0005	.02	.11	-
19	325	78	77	.18	<.01	.2	<.005	16	.04	.42	<.005	<.03	.053	19.5	.044	1.19	<.0005	.04	.23	-
20	325	105	81	.29	<.01	.2	.007	19	.04	.48	<.005	<.03	.053	19.5	.045	1.41	<.0005	.045	.23	-
21	302	105	81	.29	<.01	.2	.007	19	.02	.48	<.005	<.03	.03	17.2	.045	1.41	<.0005	.045	.22	-
22	350	50	80	.22	<.01	.2	<.005	19	.02	.33	<.005	<.03	.015	12.2	.033	.56	<.0005	.015	.08	-
23	350	50	80	.22	<.01	.2	<.005	19	.02	.33	<.005	<.03	.015	12.2	.033	.56	<.0005	.015	.08	-
24	350	50	80	.22	<.01	.2	<.005	19	.02	.33	<.005	<.03	.015	12.2	.033	.56	<.0005	.015	.08	-
25	312	113	77	.19	<.01	.3	<.005	17	.04	.41	<.005	<.03	.25	17.75	.049	1.16	<.0005	.036	.26	-
26	312	64	77	.19	<.01	.8	<.005	16	.04	.24	<.005	<.03	.06	10.25	.07	1.16	<.0005	.036	.26	-
27	312	64	76	.16	<.01	.8	<.005	16	.04	.24	<.005	<.03	.06	10.25	.07	.68	<.0005	.025	.13	-
28	312	64	76	.16	<.01	.8	<.005	16	.04	.24	<.005	<.03	.06	10.25	.07	.68	<.0005	.025	.13	-
29	262	79	70	.19	<.01	.2	<.005	16	.02	.29	<.005	<.03	.04	8.3	.25	.45	.0008	.02	.07	-
30	262	79	70	.19	<.01	.2	<.005	16	.02	.29	<.005	<.03	.04	8.3	.25	.45	.0008	.02	.07	-
31	262	79	70	.19	<.01	.2	<.005	16	.02	.29	<.005	<.03	.04	8.3	.25	.45	.0008	.02	.07	-
32	262	79	70	.19	<.01	.2	<.005	16	.02	.29	<.005	<.03	.04	8.3	.25	.45	.0008	.02	.07	-

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EPA-287 (Cin.)
(4-76)

Several reaches of these rivers experience violations of the Cu standard. The upper Illinois River also has high NH_3 background concentrations.

Future Illinois water quality problems have been predicted by the Illinois EPA (2) based on current data. Table 7.2 shows those constituents that are predicted to violate the state standard even if all planned control measures are employed.

7.2.2 Indiana

Using 1972-1976 data from the Indiana Stream Pollution Control Board (3), the general procedure described in Section 7.2 was used to estimate current water quality conditions for the Wabash and White Rivers. Water quality problem areas are listed in Table 7.3.

7.2.3 Kentucky

Using 1974, 1976, and 1977 Ohio River Valley Water Sanitation Commission (ORSANCO) data (5, 6, 7), current water quality conditions were estimated for the Green and Big Sandy Rivers. Current water quality data were not available for the Kentucky River.

Potential power plant impacts on Kentucky rivers are estimated to be relatively small since only one conjured plant in one scenario was located on the Big Sandy and since only one planned plant (440MW) was specified for the Kentucky River and only one planned plant (480MW) for the Green River. When monthly concentrations were available for these rivers, averages of concentrations during low-flow months were taken. For some constituents, however, only annual maximum and minimum concentrations were reported; in this study the maximum concentration over all three years was used.

7.2.4 Ohio

Using the averages of data obtained during 1976, the Ohio Environmental Protection Agency (8) estimated water quality conditions for the Scioto, Great Miami, Little Miami, Muskingum, and Mahoning Rivers. These 1976 averages are given in Table 7.1. The water qualtiy violations and problem areas that they reported are summarized in Table 7.4.

7.2.5 Pennsylvania

Using averages of data obtained from 1975 to 1977, current water quality conditions were estimated for the Monongahela and Allegheny Rivers. (USEPA STORET data were obtained from Sooky (10)). Water quality violations are summarized in Table 7.5.

7.2.6 West Virginia

Using averages of 1976 data (11), current water quality conditions were estimated for the Kanawha and Monongahela Rivers. Violations of standards for iron, manganese, and phenols occured on the Monongahela (11). Also, 22% of that stream is affected by acid mine drainage (11).

TABLE 7.2 EXPECTED FUTURE WATER QUALITY PROBLEMS IN ILLINOIS

River	Location	Parameters in violation of state standards[1]
Illinois	below Morris	Cr, NH_3, Fecal Coliform,[a] DO[a]
Illinois	below Chilicothe	DO, NH_3, Fecal Coliform[a]
Illinois	below Meredosia	DO, Fecal Coliform
Mississippi	below Moline	Fecal Coliform[a]
Mississippi	below St. Louis	Fecal Coliform, DO
Wabash	(see Table 7.3)	
Kankakee	below Momence	Fecal Coliform
Sangamon		Hg, Pb, DO, Fecal Coliform[a]

[1] From reference 2. Those parameter violations noted with superscript "a" have been associated with known point discharges and are expected to continue. Other parameter violations are not associated with any known dischargers.

TABLE 7.3 WATER QUALITY PROBLEM AREAS IN INDIANA[2]

River	Location(s)
West Fork, White River	Muncie to Spencer
East Fork, White River	Columbus*
Wabash River	Bluffton, Linn Grove, Wabash, Huntington,* Peru, Delphi, Terre Haute

[2] From reference 4. Existing (in 1971) and potential (indicated by an *) water quality problem areas in 1980-2000 are based on dissolved oxygen and fecal coliform estimates.

TABLE 7.4 VIOLATIONS OF WATER QUALITY STANDARDS IN OHIO[3]

River	Location	Parameters in violation of state standards
Scioto	above Columbus	DO, NH_3, Fecal Coliform
	below Columbus	DO, NH_3, Fecal Coliform, heavy metals
Great Miami	below Dayton	DO, heavy metals, NH_3, phenols, Cl, CN, Fe
Muskingum	below Massillon	Phenol, NH_3, DO, Cl, TDS
	below New Philadelphia	Cl, NH_3, Mn, Fe
Mahoning	below Warren	Fecal Coliform, NH_3, DO, Pb, Temperture, phenols, Zn, CN

[3] From references 8 and 9.

TABLE 7.5 VIOLATIONS OF WATER QUALITY STANDARDS IN PENNSYLVANIA[4]

River	County	Parameters in violation of state standards
Allegheny	Westmoreland, Clarion	Ni, Zn, Fe, Phenols
Monongahela	Fayette, Westmoreland	CN, Oil

[4] From reference 10.

7.2.7 Ohio River Main Stem

Current water quality conditions were assessed using 1974, 1976, and 1977 ORSANCO data (5, 6, 7). When monthly concentrations were available, averages of concentrations during low-flow months were taken. For some constituents, however, only annual maximum and minimum concentrations were reported; the maximum concentration over all three years was used in the analysis. Also, Table 7.6 summarizes current water quality problems on the main stem of the Ohio River.

7.3 POWER PLANT LOADINGS

7.3.1 Introduction

It was assumed in this study that new power plants will meet present liquid discharge regulations for new sources (see Table 7.7). Many potentially significant pollutants, however, are not included in those regulations, and the U.S. Environmental Protection Agency (EPA) is revising the standards.

Estimates were made of potential pollutant loadings for use in this study. Available sampling data, however, are sparse and reflect wide variations because of different power plant vintages, operation, and coals (for coal-fired plants). The major liquid waste streams from a fossil-fueled steam-electric power plant, as shown in Figure 7.1, may be classified as follows:

1) Ash pond effluent;

2) Cooling tower blowdown (if cooling towers are used);

3) Scrubber effluent;

4) Boiler blowdown;

5) Waste flow from periodic cleaning of heat transfer surfaces;

6) Coal-pile runoff.

Available sampling data from each of these streams are discussed below, and estimates of loadings for new power plants are listed. Other liquid waste streams may include waste streams from water treatment processes, biocides (e.g., Cl) in once-through cooling discharge, and miscellaneous waste flows.

7.3.2 Ash Handling

Bottom ash from the boiler and fly ash from electrostatic precipitators are transported to ash ponds. Since new source standards require zero discharge of fly ash sluice water, fly ash will be handled using a dry process in future power plants (13, 15).

Current new source regulations for bottom ash transport water limit discharges of total suspended solids (TSS) and oil and grease. The average daily standard is written as:

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(4-76)

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TABLE 7.6 VIOLATIONS OF WATER QUALITY STANDARDS FOR THE OHIO RIVER[5]

Ohio River reach between the following tributaries		Parameters in violation of ORSANCO standards
Allegheny	Muskingum	Fecal Coliform[a], Fe[a], Pb[b]
Muskingum	Scioto	Fe[b], Pb[a]
Scioto	L. Miami	TSS[a], Fe[a]
L. Miami	Salt	DO[a], Fecal Coliform[b], TSS[a], Fe[b]
Salt	Wabash	TSS[a], Fe[c], Pb[a]
Wabash	Mississippi	TSS[a], Fe[b]

[5] From reference 12. Superscripts a, b, c indicate, respectively:

[a] 25% to 50% of samples during July, 1975, to June, 1976, exceeded standard;
[b] 50% to 75% of samples during July, 1975, to June, 1976, exceeded standard;
[c] over 75% of samples during July, 1975, to June, 1976, exceeded standard.

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EPA-287 (Cin.)
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TABLE 7.7 CHEMICAL EFFLUENT GUIDELINES AND STANDARDS FOR STEAM ELECTRIC POWER GENERATING PLANTS[6, 7]

Effluent Sources	BPCTCA (1975)[8]	BATEA (1983)[9]	New source standard
All discharges - pH	6.0-9.0	6.0-9.0	6.0-9.0
Cooling systems			
Free available chlorine	.2[10]	.2[10]	.2[10]
total chlorine	not specified	.2 all times	no discharge
total phorous (as P)	not specified	.5 all times	no discharge
total zinc	not specified	1 all times	no discharge
other corrosion inhibitors	not specified	case by case	no discharge
Low volume waste water			
total suspended solids	30	30	30
oil and grease	15	15	15
Metal cleaning wastes and boiler blowdown			
Total suspended solids	30	30	30
oil and grease	15	15	15
total copper	1	1	1
total iron	1	1	1
Fly Ash transport water			
total suspended solids	30[11]	30[11]	no discharge
oil and grease	15	15	no discharge
Bottom Ash transport water			
total suspended solids	30[11]	30÷15[12]	30÷20[12]
oil and grease	15	15÷15[12]	15÷20[12]
Rainfall runoff wastewater source			
total suspended solids	50	50	50

[6] From references 13 and 14

[7] units are average daily concentration in mg/l except where indicated otherwise

[8] BPCTA-best practicable control technology currently available

[9] BATEA-best available technology economically achievable

[10] Discharge must not be for more than 2 hours in any day. The average and maximum allowable concentrations during the discharge period are 0.2 and 0.5 mg/l, respectively (14).

[11] If the limitation requires the removal of quantities of suspended solids not added by the plant, the limitation can be relaxed but effluent should not exceed the total intake of suspended solids to the plant for these systems.

[12] This standard implies recycling bottom transport water with a resulting blowdown of 1/15 and 1/20 of the recirculating flow for BATEA and New Source Standards, respectively. The effluent should contain no more than 30 mg/l total suspended solids and less than 15 mg/l of oil and grease.

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

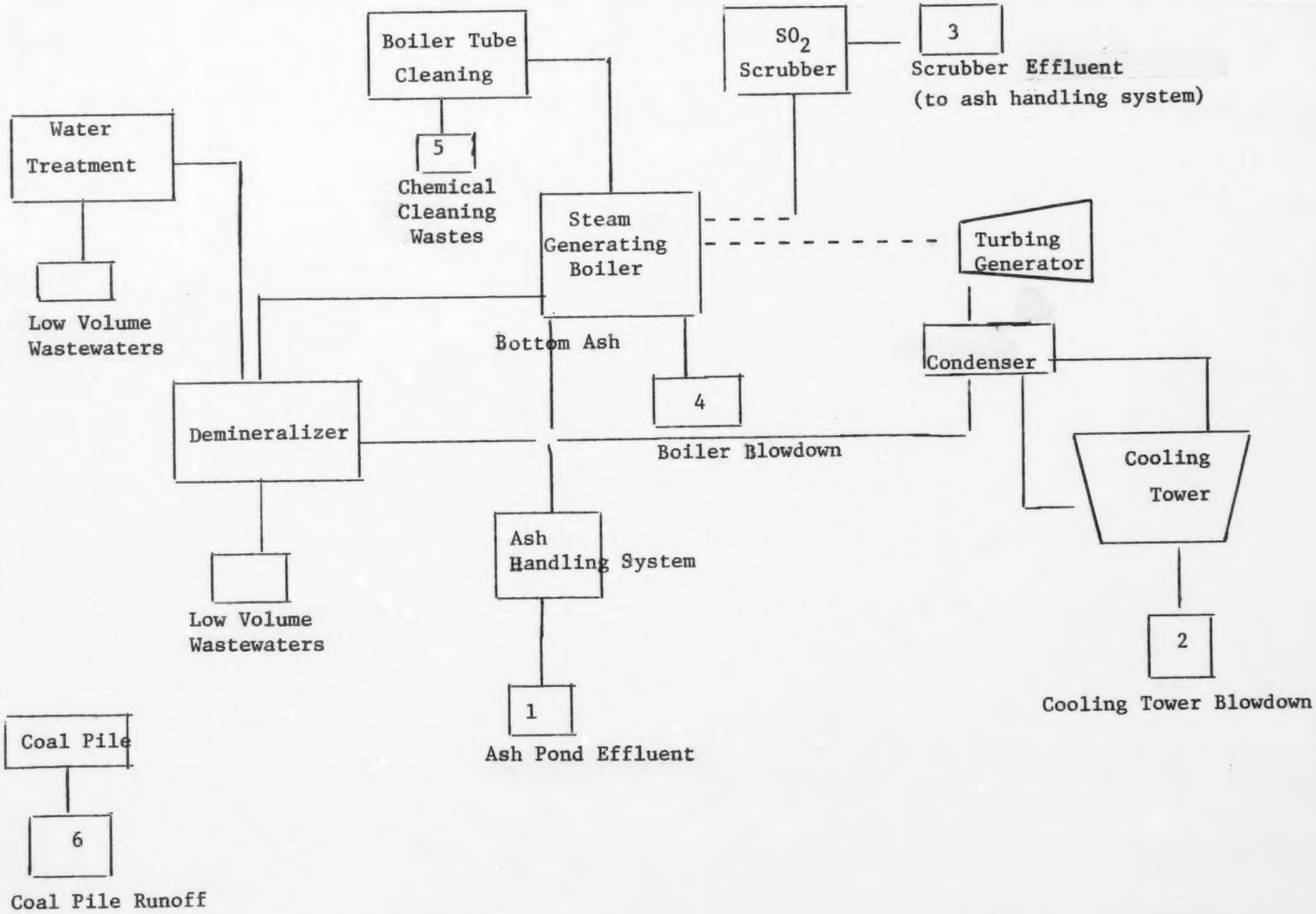
Boiler Tube Cleaning
5
Chemical Cleaning Wastes
SO_2 Scrubber
3
Scrubber Effluent (to ash handling system)
Water Treatment
Low Volume Wastewaters
Steam Generating Boiler
Turbing Generator
Bottom Ash
Condenser
Demineralizer
4
Boiler Blowdown
Cooling Tower
Ash Handling System
Low Volume Wastewaters
2
Cooling Tower Blowdown
1
Ash Pond Effluent
Coal Pile
6
Coal Pile Runoff

FIGURE 7.1 MAJOR LIQUID WASTE STREAMS FROM A FOSSIL-FUELED STEAM ELECTRIC POWER PLANT (after Reference 13)

30 ÷ 20	TSS
15 ÷ 20	oil and grease

This standard specifies that the discharge is blowdown from a recirculating ash transport system where blowdown is 5% of the recirculating flow and effluent concentration is limited to 30 mg/l and 15 mg/l for TSS and oil/grease, respectively.

Many ash pond effluents may require neutralization. Acid pond neutralization has little effect on effluent total dissolved solids (TDS) concentration (incremental [TDS] <60 mg/l) whereas alkaline pond neutralization will increase TDS concnetration in the effluent significantly (incremental [TDS] $\approx$ 300 mg/l) (16).

Table 7.8 shows ash pond effluent data from USEPA and the Tennessee Valley Authority (TVA). The EPA data are based on effluents from 19 plants, while those for TVA are based on 11 plants. Each estimate provides a loading coefficient in terms of kilograms (kg) per day per megawatt (MW).

7.3.3 Cooling Tower Blowdown

Cooling tower blowdown is necessary to prevent corrosion, scaling, and biofouling. The chemical character and flow rate of the blowdown are highly dependent on tower operation and design. For example, corrosion protection can be achieved through tower design eliminating the use of corrosion inhibitors such as chromates, phosphates, and zinc (13). Rosain (15) states that cooling towers can be operated without chemical additives, assuming average background water conditions. If new source standards of "no detectable discharge" for corrosion inhibitors (e.g., Zn, Cr, P) are enforced, the pollutant loadings of corrosion inhibitors from blowdown will not occur.

Other potential pollutant loadings could occur if other chemicals are added to the system. For example, chlorine is commonly added for control of biological growth and an acid (e.g., H_2SO_4) may be added for scale prevention. There are control options to reduce the impact of chlorine discharges (15). Chemicals, such as H_2SO_4, which prevent scale may contribute to the TDS loading from cooling towers. Assuming the use of H_2SO_4 for scale prevention, Table 7.8 shows potential sulfate loading from cooling tower blowdown. The TDS loading used in the computer analysis was 11.7 kg/(MW·day). This loading is higher than the sulfate loading listed and should perhaps be viewed as a conservatively high estimate. As discussed in Section 7.5, however, there would not be major impacts on ambient TDS levels under the various scenarios.

7.3.4 Scrubber Waste Flows

Currently, there are no standards for liquid waste effluents from scrubber systems. Recirculating scrubber systems require about 5.6 cubic feet per second (cfs)/1000 MW to replace water lost from the system because of sludge disposal, evaporation, and mist eliminator washings (16). Periodic blowdown may also be necessary. Recent investigations have indicated that liquid scrubber discharges may require treatment (22). The data for scrubber wastes in Table 7.8 are from TVA power plants which discharge scrubber wastes either

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TABLE 7.8 POWER PLANT DISCHARGES (KG/(DAY · MW))

Constituent	Boiler Blowdown	Cooling Tower Blowdown	Ash pond Effluent	Lime and Limestone Scrubber Wastes	Coal pile Drainage	Chemical Cleaning Wastes
TDS	1.27(14)		6.01(13) 10.14(14) 19.49(17)	20.67(13)	.365(13) 1.27(14)	
TSS	1.36(15)		-.64(13) .933(14) .305(17)		.10(13) .196(14)	.093(14)
Sulfate		8.53(16) 5.5(18)	3.23(13) 2.93(14)	12.18(13)	.42(13) .66(14)	.079(14)
Ammonia	.05(14)		.00325(13) .025(14)		.00023(14)	
Arsenic			.00105(13) .00037(17)	.00034(13)		
Barium			.00187(13) .021(17)			
Cadmium			.00008(13) .00017(17)	.00013(13)		
Chloride			.044(13) 1.2(14) 1.78(17)	5.92(13)	0(13) .062(14)	
Chromium	0.0068(15)		.0003(13) .0004(14) .001(17)	.00058(13)	0(13)	
Phosphorus	0.1136(15) .127(14)		.0026(14) .01(17)	.0005(13)	.0003(14)	
Selenium			.0006(13) .0002(17)	.0025(13)		
Silver			.000064(13) .00078(17)	.00069(13)		
Copper			-.0004(13) .0001(14) .049(17)	.00023(13)	.000058(13)	.00036(14)
Iron			-.0325(13) .0146(14) .0(17)	.0092(13)	.0985(13) .00008(14)	.076(14)
Lead			-.0007(13) .00027(17)	.00046(13)		
Manganese			.00011(13)	.00294(13)		

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TABLE 7.8 (CONTINUED)

Constituent	Boiler Blowdown	Cooling Tower Blowdown	Ash pond Effluent	Lime and Limestone Scrubber Wastes	Coal pile Drainage	Chemical Cleaning Wastes
Mercury			.000021(13) .000008(14) .00016(17)	.00008(13)	.000002(13)	
Nickel			.0017(13) .00042(14)	.00176(13)	.00016(13)	
Zinc			.0015(13) .00087(14) .051(17)	.00041(13)	.00037(13) .001(14)	
Boron	.905(15)					

[13] Derived from References 14 and 17.
[14] Derived from Reference 13.
[15] Derived from Reference 18.
[16] Derived from Reference 19.
[17] Derived from Reference 20.
[18] Derived from Reference 21.

EPA-287 (Cin.)
(4-76)

to ash ponds or to non-overflow scrubber ponds. Ash pond effluents were taken into account in this study, and they include scrubber waste loads in cases where scrubber wastes are routed to the ash pond.

7.3.5 Boiler Blowdown

The chemical character of boiler blowdown will vary depending on the inhibitors used for scale and corrosion. The TDS concentration from medium pressure and high pressure boilers may range from 100 to 500 mg/l and from 10 to 100 mg/l, respectively (13). Boiler water treatment with phosphates or hydrazine may contribute 5 to 50 mg/l phosphate and 0 to 2 mg/l ammonia, respectively (13). Iron and copper may also be significant pollutants in the blowdown.

Blowdown flow may be continuous or intermittent with a frequency of approximately once a day. Based on 0 to 4 gal/1000 lbs steam generated/MW hour (13) and 7000 lbs steam generated/ MW hour (23), continuous blowdown flow would be .00104 cfs/MW. Another source (13) indicates an average boiler blowdown of 8.05×10^{-5} cfs/MW.

Using the highest figures mentioned above for blowdown flow and blowdown concentrations, estimates of existing TDS, phosphates, and ammonia discharges were made and are shown in Table 7.8. Teknekron's (18) estimates of total suspended solids (TSS), chromium and boron from boiler blowdown are also shown in Table 7.8. Those estimates, instead of new source standards, were used in this study. In general, pollutant loadings from boiler blowdown are a relatively small part of the total plant loadings (except in the case of boron).

7.3.6 Metal Cleaning Wastes

In order to maintain efficient heat transfer, boiler components are cleaned periodically, every 30 months on the average (13). This study used averaged net loadings over time (see Table 7.8) as presented by EPA. There could be local impacts, however, associated with the pulse loadings associated with one cleaning.

7.3.7 Coal Pile Runoff

A coal supply of 90 days is usually maintained at a power plant (13). When coal is exposed to moisture and air, oxidation reactions (e.g., metal sulfides → H_2SO_4) take place. Sulfuric acid will appear in coal pile runoff and, if uncontrolled, would be discharged. Coal pile runoff is usually highly acidic, with high concentrations of TDS, iron, sulfate, and trace metals. Although generally little control has been practiced in the past, future controls of the runoff will likely include collection, neutralization, and sedimentation (16). Some power plants route the runoff to the ash pond where dilution, pH neutralization, and sedimentation will significantly decrease the impact on receiving waters.

Table 7.8 lists average loadings from coal pile runoff. The sampling data were highly variable because of the highly variable nature of runoff. It was assumed that runoff would be routed to the ash pond and treated. Average

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

loadings were used in this study, but there could be local impacts associated with pulse loadings if there are overflow conditions during storms.

7.3.8 Net Pollutant Loadings From Power Plants

Table 7.9 lists total net pollutant loadings for coal and nuclear power plants with cooling towers based on the loadings discussed above. Total net pollutant loadings were estimated by summing the net loadings of various waste flows which would be expected at a particular type of power plant. For example, coal-fired power plants with cooling towers have all effluent flows listed in Table 7.8, so all these waste flows contribute to a total net loading. (Scrubber waste flows are not added directly to the total net loading since scrubber waste flow is assumed to be routed to the ash pond; see Section 7.3.4.) For nuclear power plants, ash pond effluents and coal pile runoff are also deleted from the total net loading. Specifically, the loadings for TDS and sulfate would decrease to 12.7 and 3.98 Kg/(MW · day), respectively, for coal plants, and they would decrease to 12.7 and 0.08, respectively, for nuclear plants. If a power plant is assumed to use once-through cooling, the net loading associated with cooling tower blowdown would be deleted from the total net loading. Potential impacts from chlorinated once-through discharges and radioactive effluents were not considered since the focus of this study is on the use of cooling towers.

7.4 METHODOLOGY

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7.4.1 Computational Procedure

All constituents were assumed to be conservative so that an upper bound on downstream impacts could be evaluated. Although it was beyond the scope of this project to develop complex models to determine ambient concentrations of degradable or nonconservative pollutants, conclusions about the potential regional impacts of the various scenarios could be made by using the upper bounds on the impacts. Power plant effluents and river flows were assumed constant. The effluent loadings given in Table 7.9 were applied to 7-day 10-year low-flow estimates for the rivers, which were divided into reaches. The 7-day 10-year low flows listed in Chapter 2 were adjusted for each scenario to take projected water consumption into account, as discussed in Chapter 6, in calculating an estimate of the potential increase in concentration of each constituent. The mass balance equation used to obtain the upper bound estimates on the concentration of each constitutent in each reach is:

$$C = \text{BKGD} \frac{(Q)}{(Q')} + \sum_{\forall j} \frac{.4087\,(\text{MW}_j)(\text{LOAD}_j)}{Q'}$$

where

C = upper bound on the concentration of a given constituent (mg/l),
BKGD = background concentration of that constituent in the reach (mg/l) (see Section 7.2),
Q = 7-day 10-year low flow (cfs) (see Chapter 2),
Q' = Q less consumption in that reach and upstream (cfs) (see discussion below),

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(4-76)

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TABLE 7.9 POLLUTANT LOADINGS FROM POWER PLANTS USING EXISTING CONTROLS (kg/(MW·day))

Constitutent	Coal Plant with Cooling Towers	Nuclear Plant with Cooling Towers
TDS	24.4	12.97
TSS	2.57	1.45
Sulfate	12.5	8.60
Ammonia	.075	.05
Arsenic	.0011	0
Barium	.0019	0
Cadmium	.00008	0
Chloride	1.23	0
Chromium	.0072	.0068
Phosphorus	.130	.127
Selenium	.0006	0
Silver	.00007	0
Copper	.002	.00036
Iron	.189	.0757
Lead	0	0
Manganese	.00006	0
Mercury	.000023	0
Nickel	.0018	0
Zinc	.0047	0
Boron	.905	.905

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EFA-287 (Cin.)
(4-78)

MW_j = sum of power plant capacities in megawatts of type j sited in that reach and upstream under the given scenario (MW) (see Table 7.9 for a list of the types of plants),

$LOAD_j$ = pollutant load per megawatt of type j (see Table 7.9) contributed to the river (kg/day · MW).

The several combinations of estimates of Q' and load were used in the mass balance calculations. One estimate of Q' was obtained by taking into account only the power plant consumption in the reach and upstream (see Chapter 4 for power plant consumption estimates); assessments using this approach were designed to evaluate the potential impacts of each scenario without assuming future increases in water consumption for other purposes. Q' was also estimated taking into account projected water consumption for municipal and industrial purposes (see Chapter 3). The incremental effect of power plant effluents is greater under those conditions since streamflows are somewhat lower.

The $LOAD_j$ was assumed to be one of three values: 100%, 5%, or 0% of the net loadings shown in Table 7.9. A loading of 100% assumes lax controls, i.e., the effluent levels will be as given in Table 7.9; such loadings are not expected in the future because of new source regulations and current design practices. (This case was not evaluated in the analysis described in Section 7.5, although summary results are given in Table 7.12.) The 5% loadings case reflects additional recycle and waste treatment typical of current practices. New regulations, such as those requiring recycle of ash transport waters (13, 15), will likely lead to significant reductions in loadings, although data are not currently available. Calculations using 0% loadings were used to evaluate water quality impacts from power plant consumption alone, i.e., the increase in ambient concentrations resulting from decreased streamflows. These estimates were conservative in that it was assumed that the mass would be constant and that only the volume of water would decrease. This approach is appropriate in situations where upstream water consumption decreases the streamflow available for diluting downstream discharges; it is also appropriate in cases where consumptive losses, such as evaporative cooling, do not carry pollutants. The method is least appropriate in cases where "consumptive" losses, such as drift from a cooling tower or leaks from a municipal or industrial system, do decrease the discharge of pollutants to the waterway.

7.4.2 Reference Standards for Water Quality

Water quality standards vary from state to state and from river to river, but in this study one reference standard was used for each constituent to examine potential impacts on regional water quality by power plant discharges. The reference standard was selected considering the water quality criteria of Illinois, Indiana, Ohio, Kentucky, Pennsylvania, West Virginia, ORSANCO, and USEPA for domestic and aquatic uses. (Water quality standards are currently being reviewed throughout the ORBES region.) Table 7.10 lists the reference standards used for 20 constituents as well as the standards from each state and criteria from ORSANCO and USEPA. For most of the constituents, the reference standard represents the minimum of all state standards or EPA criteria and provides a uniform baseline for evaluating alternative regional scenarios.

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TABLE 7.10 REFERENCE STANDARDS AND WATER QUALITY STANDARDS IN EFFECT IN ORBES REGION

Constituent	Reference Standard (mg/1)	U.S.EPA(19) Criterion (mg/1)		ORSANCO(20) Criterion (mg/1)	STATE STANDARD (mg/1)							
					Ill(21)		Ind(22)	Kent(23)	Ohio(21)		Penn(24)	W Va(25)
		Domestic	Aquatic		Domestic	General			Domestic	Aquatic		
TDS	500	250(26)	N	500	500	1000	750	500	500(27) (150)	1500(27) (150)	500	N
TSS	50	(28)	N	N	N	N	N	N	N	N	N	N
Sulfate	250	(see 26)	N	250	250	500	250	N	250	N	250	N
Ammonia	1.10	1.1(29)	N	N	N	1.5	N	N	N	1.4(30)	.5	N
Arsenic	.05	.05(31)	N	.05	.1	1.0	N	.05	.05	N	.05	.01
Barium	1.0	1.0	N	1.0	1.0	5.0	N	1.0	1.0	N	N	.50
Cadmium	.01	.01	(32)	.01	.01	.05	N	.01	.01	.012	N	.01
Chloride	250	(see 26)	N	250	250	500	250	N	250	N	150	100
Chromium	.01	.05	.01	.05(33)	.05	1.05	N	.05(33)	.05	.1	.05	.05(33)
Phosphorus	.05	N	N	N	N	.05	N	N	N	N	N	N
Selenium	.01	.01	.01L	.01	.01	1.0	.01L	.01	.01	.01L	N	.01
Silver	.005	.05	.01L	.05	N	.005	.01L	.05	.05	.01L	N	.05
Copper	.06	1.0	.1L	.1L	N	.02	.1L	.1L	1.0	.06(34)	.1L	.1L
Iron	.30	.30	1.0	N	N	1.0	N	N	.3	1.0	1.5	N
Lead	.05	.05	.01L	.05	.05	.1	.01L	.05	.05	.03	.05	.05
Manganese	.05	.05	.1	N	.05	1.0	N	N	.05	N	1.0	N
Mercury (µg/1)	.05	2.0	.05	.2	N	.5	N	N	2.0	.05	N	N
Nickel	1.00	N	.01L	N	N	1.0	.01L	.1L	N	.01L	.01L	.1L
Zinc	.205	5.0	.01L	.01L	N	1.0	.01L	.1L	5.0	.205(34)	.01L	.1L
Boron	1.00	(35)	N	N	N	1.0	N	N	N	N	N	N

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 7.10 FOOTNOTES

19 From Reference 24. Also, N indicates no standard, and L indicates the 96 hour LC_{50}.

20 From Reference 25.

21 From Reference 26, toxic substance < .1(96LC_{50}) or .1(96 hour median tolerance limit).

22 From Reference 27

23 From Reference 28

24 From Reference 10.

25 From Reference 29, assuming Kanawha River criteria, and all toxic substances < .1 x (96 hr. median tolerance limit).

26 For chlorides and sulfates.

27 May exceed one but not both of the following:
(A) 1500 mg/1
(B) 150 mg/1 attributable to human activities.

28 Does not reduce depth of compensation point for photosynthetic activity by more than 10% from norm.

29 Based on .02 un-ionized NH_3 with PH = 7.5 T = 25°C.

30 Based on .05 mg/1 un-ionized NH_3 at PH = 7.8, T = 25°C.

31 .100 for irrigation.

32 Standard (mg/1)

soft water	hard water	type of aquatic life
.0004	.0012	for cladocerans, salmonid fish
.004	.012	less sensitive aquatic life

33 As hexavalent Cr.

34 Based on total hardness = 260-280 mg/1 as $CaCO_3$ and .1 (96 LC_{50}) if Cu and .01(96LC_{50}) if Zn.

35 .75 for irrigation on sensitive crops.

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EPA-287 (Cin.)
(4-76)

7.5 WATER QUALITY IMPACTS

7.5.1 Introduction

The potential water quality impacts on each river under each scenario are discussed in this section. The total (planned plus conjured) plant capacities are listed in Table 7.11 for each case considered. Note that Scenario 2 can be viewed as a base case and that many other scenarios reflect additions or subtractions from it. The plant capacities specified for many rivers under various scenarios, however, are identical to those under Scenario 2. Thus, Scenario 2 is discussed first, and the detailed discussions by river of other scenarios are presented using comparisons with Scenario 2.

Scenarios 2a and 2b add additional coal-fired and nuclear plant capacity, respectively. Scenario 5 is similar to Scenario 2; the only change is that some of the conjured plants are eliminated. Scenario 3 is similar to 2 except that more plants are eliminated than under Scenario 5. Scenario 4 is similar to the scenarios mentioned above; it, however, specifies the least plant capacity. Scenario 1 specifies less total capacity than Scenario 2, but the most important difference between this scenario and all others is that the plant locations are dispersed. Fifteen plants were located in counties with no significant river flows; these plant capacities are not included in the figures given in Table 7.11. Also, under Scenario 1 many plants were located on the smaller tributaries in the Ohio Basins where greater impacts would result.

7.5.2 Application of the Analysis Approach

The procedure described in Section 7.4 was used to estimate an upper bound on the potential increase in the concentration of each constituent in each reach of each river under each scenario. This information was processed to select key impacts, and a table that provides information about each constituent was developed for each river under each scenario for a given plant loading condition. Specifically, the various reaches were examined in each case and the greatest potential impacts were listed.

An example of these tables is given in Figure 7.2, which shows the computer output for the Ohio River under Scenario 2. (Although it is labeled Ohio River, this output also includes information for two reaches of the Mississippi River below the confluence with the Ohio River.) The output is for the case where plant loadings were assumed to be 5% of the values given in Table 7.9.

Column 1 lists the constituents considered. Note that all constituents were viewed as being conservative in all calculations. However, many of the constituents (e.g., ammonia) are not conservative; therefore the information provided for them can only be used as upper limits on actual ambient concentrations. These limits are useful because in many cases they imply that there are no significant impacts.

Column 2 lists the reference standards used for the various constitutents (see Section 7.4.3) in carrying out the assessment. This standard is not necessarily the state standard that applies to a given river.

EPA-287 (Cin.)
(4-76)

TABLE 7.11 POWER PLANT CAPACITY FOR EACH RIVER UNDER EACH SCENARIO

	Power Plant Capacity (Planned MW) (Conjured MW)						
	Scenario						
River	2	2a	2b	5	3	4	1
Illinois	15,155 5,200	(2)[36]	15,155 6,200	15,155 3,250	15,155 2,600	15,155 650	15,155 1,950
Big Muddy	346 0	(2)	(2)	(2)	(2)	(2)	(2)
Rock	0 1,300	(2)	(2)	(2)	(2)	-	(2)
Mississippi (above Ohio R.)	15,721 7,800	(2)	15,721 8,800	15,721 5,850	15,721 4,550	15,721 1,300	(3)
White	1,535 0	(2)	(2)	(2)	(2)	(2)	1,535 1,950
Wabash	6,932 2,600	(2)	(2)	(2)	(2)	(2)	6,932 5,850
Big Sandy	(37)	-	-	-	-	-	0 650
Green	480 0	(2)	(2)	(2)	(2)	(2)	(2)
Kentucky	440 0	(2)	(2)	(2)	(2)	(2)	(2)
Scioto	90 1,300	90 2,600	(2)	90 650	90 0	(3)	(2)
Muskingum	1,826 1,950	1,826 3,250	(2)	(2)	(2)	1,826 650	1,826 0
Whitewater	160 0	(2)	(2)	(2)	(2)	(2)	160 650
Great Miami	160 0	(2)	(2)	(2)	(2)	(2)	160 650
Little Miami	-	-	-	-	-	-	0 650
Beaver	0 1,950	0 2,600	(2)	(2)	0 650	- -	0 -

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FOR TABLES AND ILLUSTRATIONS

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 7.11 (CONTINUED)

	Power Plant Capacity (Planned MW) (Conjured MW)						
			Scenario				
River	2	2a	2b	5	3	4	1
Allegheny	5,659 4,550	5,659 7,150	5,659 8,550	5,659 3,250	(5)	5,659 650	5,659 7,150
Monongahela	2,470 1,950	(2)	2,470 3,950	(2)	(2)	(2)	2,470 1,950
Susquehanna	0 650	(2)	(2)	-	(2)	-	(2)
Kanawha	2,931 0	(2)	(2)	(2)	(2)	(2)	2,931 650
Ohio	59,006 53,300	59,006 73,450	59,006 72,300	59,006 44,850	59,006 37,700	59,006 20,800	59,006 46,800
ORBES Region	74,727 61,750	74,727 81,900	74,727 81,750	74,727 50,700	74,727 42,900	74,727 22,100	74,727 52,000

36 (2) indicates that this scenario is identical to the scenario indicated, Scenario 2 in this case.

37 - indicates that there is no planned or conjured plant capacity.

EPA-287 (Cin.)
(4-76)

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OHIO       RIVER        32 REACHES; 7Q10 FROM 6558. TO 93833. CFS;  65732. MW PLANNED +  61100. MW CONJURED=126832. MW TOTAL

                                      REACHES IN VIOLATION   ________INCREASE IN CONCENTRATION  (MG/L)________
                                                                                                                 NEW VIOL.     MAX INC CON
                REFERENCE   BKGD IN LAST                                   (MAX OVER ALL REACHES)                MSI AND       XS % OF STD
CONSTITUENT      STANDARD      REACH     AVG HIGH   BACKGRD     PLANT     PLANT   LD+CONS    PLANT LD+CONS+MSI CONS  PLANTS  MSI   AVG    HIGH
                   MG/L        MG/L      LD  LD     MSI EX.     CONS       AVG      HIGH        AVG      HIGH        AVG HI ONLY   LD      LD
-------------------------------------------------------------   ----------------------------------------------------------------------  -------

TOT DIS S.    500.00000   262.500000    0 ( 0)     0 ( 0)     26.029    29.494( 31.434)    32.061( 34.093)
TOT SUS S.     50.00000    79.000000   27 (27)    23 (20)      7.783     8.122(  8.355)     8.792(  9.035)   A   H   *    10      10
SULFATE       250.00000    70.000000    0 ( 0)     0 ( 0)      6.115     8.951(  9.831)     9.641( 10.563)
AMMONIA         1.10000      .190000    0 ( 0)     0 ( 0)       .029      .038(   .048)      .042(   .053)
ARSENIC          .05000      .010000    0 ( 0)     0 ( 0)       .001      .001(   .001)      .001(   .001)
BARIUM          1.00000      .200000    0 ( 0)     0 ( 0)       .056      .057(   .057)      .061(   .062)
CADMIUM          .01000      .005000    4 ( 4)     4 ( 4)       .002      .002(   .002)      .003(   .003)                 25      25
CHLORIDE      250.00000    16.000000    0 ( 0)     0 ( 0)      1.643     2.021(  2.464)     2.108(  2.651)
CHROMIUM         .01000      .020000   32 (32)    32 (32)       .006      .006(   .007)      .007(   .007)                 50      50
PHOSPHORUS       .05000      .290000   32 (32)    32 (32)       .034      .051(   .052)      .056(   .056)                 50      50
SELENIUM         .01000      .005000   18 (18)    18 ( 0)       .001      .001(   .001)      .001(   .001)   A   H   *            10
SILVER           .00500      .030000   14 (14)    14 (14)       .002      .002(   .002)      .002(   .003)                 25      50
COPPER           .06000      .040000   18 (19)    18 (14)       .026      .026(   .026)      .028(   .029)   A   H   *    25      25
IRON             .30000     8.300000   32 (32)    32 (32)      1.376     1.401(  1.413)     1.524(  1.536)                 50      50
LEAD             .05000      .250000   28 (28)    26 (24)       .046      .046(   .046)      .049(   .049)   A   H   *    50      50
MANGANESE        .05000      .450000   32 (32)    32 (32)       .237      .237(   .238)      .263(   .264)                 50      50
MERC(UG/L)       .05000      .800000   32 (32)    32 (32)       .100      .102(   .114)      .108(   .121)                 50      50
NICKEL          1.00000      .020000    0 ( 0)     0 ( 0)       .006      .006(   .006)      .006(   .007)
ZINC             .20500      .070000   16 (16)    14 (14)       .022      .022(   .025)      .024(   .027)   A   H        10      10
BORON           1.00000   **********    *    *     *    *       *         .132(   .132)      .138(   .138)   -   -   -    10      10
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FIGURE 7.2. EXAMPLE SUMMARY TABLE OF POTENTIAL WATER QUALITY IMPACTS

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

Column 3 provides the background concentration (see Section 7.2) of each constituent in the last reach of the river. Although the background concentration is likely to vary from reach to reach of a river for a given constituent, the information shown is useful in making assessments. If the background level was not available, a series of asterisks is printed; see, for example, the row for boron in Figure 7.2.

Columns 4-7 provide information about violations of the reference standard. Column 7 indicates the number of reaches for which the background level exceeds the standard. Column 6 indicates the number of reaches that would be in violation of the standard when municipal and industrial (M & I) consumption is taken into account (see Section 7.4). Column 4 indicates the number of reaches that would be in violation when plant loadings and consumption as well as M & I consumption are considered (column 5 is similar to column 4, except that higher estimates of power plant emissions were used; these results were not used in the final assessment.) For example, in Figure 7.2, these columns indicate that in 24 of the 32 reaches the background levels would violate the standard for lead. Two additional reaches would violate the standard as a result of M & I consumption, and another two would violate the standard when the plant consumption and loadings are also considered.

Columns 8-12 provide information about the reaches for which the maximum concentration increases occur. Column 8 indicates the maximum increase in concentration of each constituent that would result from power consumption alone. This column in Figure 7.2 indicates, for example, that in at least one reach the concentration of lead would increase 0.046 mg/l if the background condition are modified to reflect the concentrating effect of plant consumption. Note that M & I consumption was not taken into account in calculating this number; the 7-day 10-year low flow was modified only to reflect plant consumption.

Column 9 indicates the maximum increase that would result from plant consumption and loadings, without considering M & I consumption. As an example, Figure 7.2 indicates that plant loadings are insignificant in comparison to plant consumption for most constituents for the 5% plant loading case. (Column 10 provides similar information for a set of higher estimates of plant loadings, but those estimates were not used in the final assessment.)

Column 11 lists the maximum increase that would result from plant consumption and loadings under the assumption that the 7-day 10-year low flow would be reduced to reflect projected M & I consumption. The basis for calculating the increase is not the original background level (as in column 9) but instead is the background level that would result if the 7-day 10-year low flow values are reduced to account for projected M & I consumption. Because the flows are reduced, the effects of plant consumption and loadings are always greater in column 11 than in column 9—unless there is no projected M & I and as a result the increases listed in the two columns are the same. For example, the increase in the concentration of lead as a result of plant consumption and loadings would be 0.049 mg/l if the base flow is assumed to be decreased to reflect M & I consumption. (Column 12 provides similar information for the set of higher estimates of plant loadings.)

Columns 13-15 provide summary information about new projected violations of the reference standard. In column 13, an A is used to indicate a case where there would be at least one new violation of the reference standard as a result of projected M & I consumption and power plant consumption and loadings. (If the number in column 4 exceeds the number in column 7, an A is shown.) For example, Figure 7.2 indicates that there would be at least one reach with a new violation of the standard for lead. (In column 14 an H indicates at least one new violation under the set of higher plant loadings.) In column 15 an asterisk indicates that at least one new violation would occur, however, as a result of M & I consumption alone. (If the number in column 6 exceeds the number in column 7 , an asterisk is shown.) Figure 7.2 indicates, for example, that in at least one reach a new violation of the standard for lead would result from M & I consumption. More detailed information, of course, can be obtained by examining columns 4, 6, and 7, as discussed above for lead. The summary information in columns 13-15 is designed for preliminary scanning of the computer output.

Column 16 indicates the level of significance of the maximum increase over all reaches in the concentration of each constituent as a result of power plant consumption and loading. The increase given in column 11 (which is calculated after adjusting river flow to account for projected M & I consumption) is compared to the reference standard. If the increase equals or exceeds 50% of the reference standard, then the number 50 is printed. If the increase does not equal or exceed 50% of the standard, but does equal or exceed 25% of the standard, then the number 25 is printed. In the analogous situation involving 10% of the standard, the number 10 is printed. This information was used in developing the material presented in Table 7.12 below for each scenario for each river. In Table 7.12, the 25% and 50% categories are combined. (Column 17 presents similar information for the set of higher plant loadings.)

It is very important to note that the increase in concentration of a given constituent could be very significant in comparison to the reference standard but still be insignificant in terms of environmental impact. This situation could occur in cases where the background concentration is very high. As a typical example, in Figure 7.2 the increase in the concentration of iron is listed as greater than 50% of the reference standard (0.3 mg/l). The maximum increase is 1.5 mg/l, which is attributed largely to plant consumption. The significant increase occurs, however, because of the high background concentration (e.g., 19.5 mg/l in one reach). With such a high background level, consumption of approximately 7% of the 7-day 10-year low flow would produce a concentration increase greater than 50% of the reference standard. The increase of 1.5 mg/l is much less significant, however, when compared to the background level.

The tables, like the one in Figure 7.2, represent a major product of this special study and were provided to Hugh T. Spencer, a member of the ORBES core team, as background information for the impact assessment carried out at the University of Louisville. A copy of each table has also been provided to the ORBES project office and is available for inspection. [Note that the numbers shown in the computer output were calculated assuming early estimates of chloride loadings of 2.8 and 1.57 kg/MW · day for coal and nuclear plants with

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

cooling towers, respectively. The calculations were not repeated using the smaller loadings given in Table 7.9; as shown below the effects of the larger loadings are insignificant, and they would be even less important under the smaller loadings.]

Several results of the analysis were also evaluated in this special study, and a discussion of these results is given in the following sections. As part of the evaluation, the key potential impacts were summarized in Table 7.12. For each scenario the major impacts are listed for each river. Note that the range of the low flow values for the various reaches of each river is also listed; planned and conjured plant capacities are also shown. The remaining columns list the constituents for which the upper bound on the estimated increase in concentration represents a significant portion of the reference standard under different loading conditions.

The first of these columns lists those constituents for which the increase in concentration would be significant under 0% loadings, i.e., only the effect of plant consumption is taken into account. The base flow used in the calculations was modified to reflect projected M & I consumption prior to calculating the increases in concentration that would result from plant consumption. Thus, as examples, in the Illinois River under Scenario 2 the concentrations of Fe and Cu would increase by amounts that exceed or equal 25% and 10%, respectively, of the reference standard.

The next column indicates additional potential impacts if 5% plant loadings are also considered. (These loadings are 5% of the values given in Table 7.9; see Section 7.4.1). These incremntal effects are generally not very significant, as discussed in more detail in the following sections. (All impacts that would occur under the 0% plant loadings, of course, would also occur under plant consumption and 5% plant loadings.) In the case of the Illinois River under Scenario 2, for example, there could be additional impacts associated with Cr and B.

The last column indicates the incremental impacts that would represent a significant portion of the reference standard if plant loadings are assumed to be 100% of the values given in Table 7.9. In general, there are many additional significant increases in the various constituents. Such high loadings are not expected, however, because of current and expected government regulations and because of current design practices.

In this evaluation, the projected increases for phosphorus (P) and total suspended solids (TSS) were not considered in the following section. The reference standard listed in Table 7.10 for P was developed for lakes and most likely would not apply to the rivers considered. All rivers with background information available have reaches with P concentrations that greatly exceed the reference standard—in many cases by a factor of 10. Also, TSS was included in the analysis and is listed in Figure 7.2; the impacts of TSS, however, are usually local in nature and the analysis did not suggest any important regional issues.

The information in Table 7.12 is discussed for each river for each scenario in the following section. Only the 0% and 5% plant loading cases are

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 7.12 SUMMARY OF WATER QUALITY IMPACTS UNDER ORBES SCENARIOS(37)

SCENARIO 2

River	Level of Significance	Constituents with Significant Concentration Increases		
		0% Loading	5% Loading	100% Loading
Illinois				
451 to 3601 cfs[38]	25%	Fe, Mn,	Cr, B	TDS^*, SO_4, NH_3, Cr^*, Fe^*, B^*, Hg^*
15,155 (5,200)[39]	10%	Cu, Pb, Hg		Se, Cu
Big Muddy				
37 to 37 cfs	25%			SO_4^*, NH_3, Cr^*, Se, Fe, Hg^*, B^*
346 (0)	10%	(TDS^*)	Cr, Fe, Hg, B	TDS^*
Rock				
1306 cfs	25%	Background Concentrations Not available		Cr, Fe, B
0 (1300)	10%			Hg
Mississippi				
15725 to 47412 cfs	25%	Hg, Fe^*		Cr, B
15,721 (7,800)	10%	Mn		
White				
155 to 685 cfs	25%			Cr^*, Fe, Hg, B
1535 (0)	10%	Fe, Hg		SO_4, NH_3
Wabash				
130 to 2498 cfs	25%	Fe, Hg		SO_4, NH_3, Cr, Se, Fe, Hg, B
6,932 (2,600)	10%	(Cd^*)	Cr, B	TDS^*, Cu, Zn
Big Sandy				
26 to 59 cfs		-	-	-
0 (0)				
Green				
306 to 500 cfs	25%	Mn		Cr, Fe, B
480 (0)	10%	Fe		Hg
Kentucky				
113 to 164 cfs	25%	Background Concentrations Not Available		Cr, Fe, B, Hg
440 (0)	10%			SO_4, NH_3, Se
Scioto				
48 to 337 cfs	25%	Cr, Ag, Fe, Mn, Hg		Cr, Fe, B
90 (1300)	10%	(TDS^*), (Cd^*), (Se^*), Pb		TDS^*, SO_4, NH_3, Se^*

TABLE 7.12 (CONTINUED)

SCENARIO 2

River	Level of Significance	Constituents with significant concentration increases 0% Loading	5% Loading	100% Loading
Muskingum				
551 to 566 cfs	25%	Cr, Ag, Fe, Pb, Mn, Hg		SO_4, Fe, Hg, B
1826 (1950)	10%	(TDS^*), (Cd^*), (Se^*)	B	TDS^*, NH_3, Cd^*, Se^*, Cu, Zn
Whitewater				
82 cfs	25%			Cr, Fe, Hg, B
160 (0)	10%			
G. Miami				
58 to 281 cfs	25%	Fe		Fe
160 (0)	10%			Cr, Hg, B
L. Miami				
27 cfs				
0 (0)		-	-	-
Beaver				
86 to 232 cfs	25%	Cr, Ag, Cu^*, Fe Mn, Hg		TDS, SO_4, NH_3^*, Se^*, B
0 (1950)	10%	NH_3^*, (Cd^*), Se^*, Pb^*, Zn^*	B	As, Cd^*
Allegheny				
470 to 1098 cfs	25%	Cr, Fe, Mn, Hg	B	TDS, SO_4, NH_3, As, Se^*, Cu^*, Fe, Hg
5,659 (4,550)	10%	TDS, As, Se^*, Cu, Pb		Zn^*
Monongahela				
384 to 459 cfs	25%	Cr, Fe, Mn, Hg, Zn		TDS, SO_4^*, NH_3, Se^*, Cu, B
2,470 (1,950)	10%	Se^*, Pb^*	Cd, B	As
Susquehanna				
136 to 136 cfs	25%			Cr, Fe, Hg, B
0 (650)	10%			TDS, SO_4, NH_3, Se
Kanawha				
1106 to 1285 cfs	25%	Hg	Fe	Cr, B
2,931 (0)	10%	(Cd^*), (Se^*), Mn, Fe, Pb^*		
Ohio				
6558 to 93833 cfs	25%	Cd, Cr, Ag, Cu^*, Fe, Pb^*		SO_4, Ag, Cr, Cu^*, Fe, Hg, B
59,006 (53,300)	10%	Zn^* Mn, Hg	B	TDS, NH_3, Se^*, Zn^*

EPA-287 (Cin.)
(4-76)

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EPA-287 (Cin.) (4-76)

TABLE 7.12 (CONTINUED)

SCENARIO 2a

River	Level of Significance	Constituents with significant concentration increases: 0% Loading	5% Loading	100% Loading
Illinois			Same as Scenario 2	
Big Muddy			Same as Scenario 2	
Rock			Same as Scenario 2	
Mississippi 15,725 to 47,412 cfs	25%	Hg, Fe*		Cr, B
15,721 (7,800)	10%	Ag, Mn		
White			Same as Scenario 2	
Wabash			Same as Scenario 2	
Big Sandy 26 to 59 cfs			Same as Scenario 2	
Green			Same as Scenario 2	
Kentucky			Same as Scenario 2	
Scioto 48 to 337 cfs	25%	Cr, Ag, Fe, Mn, Hg		TDS*, SO_4, NH_3, Se*, Fe, B
90 (2,600)	10%	(TDS*), (Cd*), Se*, Pb	B	Cd*, Cu, Zn
Muskingum 551 to 566 cfs	25%	Cr, Ag, Fe, Pb, Mn, Hg		TDS*, SO_4^*, NH_3, Se*, Fe, Hg, B
1,826 (3,250)	10%	(TDS*), Cd*, (Se*)	TDS*, Se*, B	Cd*, Cu, Zn
Whitewater			Same as Scenario 2	

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TABLE 7.12 (CONTINUED)

SCENARIO 2a

River	Level of Significance	Constituents with significant concentration increases 0% Loading	5% Loading	100% Loading
G. Miami			Same as Scenario 2	
L. Miami			Same as Scenario 2	
Beaver 86 to 232 cfs	25%	Cr, Ag, Cu^*, Fe, Mn, Hg	B	TDS^*, SO_4^*, NH_3^*, Se^*, Zn^*
0 (2600)	10%	TDS, NH_3^*, Cd^*, Se^*, Pb^*, Zn^*	$\hat{S}O_4$	As, Cl
Allegheny 470 to 1098 cfs	25%	Cr, Fe, Mn, Hg	B	TDS, SO_4, NH_3^*, As, Se^*, Cu^*, Fe, Hg
5,659 (7,150)	10%	TDS, As, Se^*, Cu, Pb, Zn^*		Cd, Ag, Zn
Monongahela			Same as Scenario 2	
Susquehanna			Same as Scenario 2	
Kanawha			Same as Scenario 2	
Ohio 6558 to 93833	25%	Cd, Cr, Ag, Cu^*, Fe, Pb^*, Mn, Hg		SO_4, NH_3, Cr, Se^*, Cu^*, Fe, Hg, B
59,006 (73,450)	10%	TSS^*, Zn^*	B, $\hat{S}e$	TDS, Zn^*

EPA-287 (Cin.)
(4-76)

TABLE 7.12 (CONTINUED)

SCENARIO 2b

River	Level of Significance	Constituents with significant concentration increases 0% Loading	5% Loading	100% Loading
Illinois 451 to 3601 cfs	25%	Fe, Mn,	Cr, B	TDS*, SO_4, NH_3, Cr*, Fe*, B*, Hg*
15,155 (6,200)	10%	Cu, Pb, Hg		Se, Cu
Big Muddy			Same as Scenario 2	
Rock			Same as Scenario 2	
Mississippi 15725 to 47412 cfs	25%	Hg, Fe*		Cr, B
15,721 (8,800)	10%	Ag, Pb, Mn		
White			Same as Scenario 2	
Wabash			Same as Scenario 2	
Big Sandy			Same as Scenario 2	
Green			Same as Scenario 2	
Kentucky			Same as Scenario 2	
Scioto			Same as Scenario 2	

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 7.12 (CONTINUED)

SCENARIO 2b

River	Level of Significance	Constituents with significant concentration increases 0% Loading	5% Loading	100% Loading
Muskingum			Same as Scenario 2	
Whitewater			Same as Scenario 2	
G. Miami			Same as Scenario 2	
L. Miami			Same as Scenario 2	
Beaver			Same as Scenario 2	
Allegheny 470 to 1098 cfs	25%	Cr, Fe, Pb, Mn, Hg	B	TDS, SO_4, NH_3, As, Cu^*, Fe, Hg, Zn^*, Se^*
5,659 (8,550)	10%	TDS, As, Se^*, Zn^*, Cu		Cd, Ag
Monongahela 384 to 459 cfs	25%	Cr, Se^*, Fe, Pb^*, Mn, Hg, Zn	B	TDS, SO_4^*, NH_3^*, Cu^*
2,470 (3,950)	10%	TDS, SO_4, NH_3, Cd, Cu	Cd^*	As, Ag
Susquehanna			Same as Scenario 2	
Kanawha			Same as Scenario 2	
Ohio 6558 to 93833 cfs	25%	Cd, Cr, Ag, Cu, Fe, Pb^*		SO_4, NH_3, Cr, Se^*, Cu^*, Fe, Hg, B
59,006 (72,300)	10%	Se^*, Zn^*	B	TDS, Zn^*

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TABLE 7.12 (CONTINUED)

SCENARIO 5

River	Level of Significance	Constituents with significant concentration increases 0% Loading	5% Loading	100% Loading
Illinois 451 to 3601 cfs	25%	Fe, Mn,	B	TDS^*, SO_4, NH_3, Cr^*, Fe^*, B^*, Hg^*
15,155 (3,250)	10%	Cu, Pb, Hg	Cr	Se, Cu
Big Muddy			Same as Scenario 2	
Rock			Same as Scenario 2	
Mississippi 15,725 to 47,412 cfs	25%	Hg, Fe^*		Cr, B
15,721 (5,850)	10%	Mn		
White			Same as Scenario 2	
Wabash			Same as Scenario 2	
Big Sandy			Same as Scenario 2	
Green			Same as Scenario 2	
Kentucky			Same as Scenario 2	
Scioto 48 to 337 cfs	25%	Ag, Fe, Mn, Hg	Cr	Fe, B
90 (650)	10%	(TDS^*), (Cd^*), Cr, (Se^*)		TDS^*, SO_4, NH_3, Se^*

PAGE NUMBER
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TABLE 7.12 (CONTINUED)

SCENARIO 5

River	Level of Significance	Constituents with significant concentration increases 0% Loading	5% Loading	100% Loading
Muskingum			Same as Scenario 2	
Whitewater			Same as Scenario 2	
G. Miami			Same as Scenario 2	
L. Miami			Same as Scenario 2	
Beaver			Same as Scenaro 2	
Allegheny 470 to 1098 cfs	25%	Cr, Fe, Mn, Hg	B	TDS, SO_4, NH_3, As, Se*, Cu*, Fe, Hg
5,659 (3,250)	10%	TDS, As, (Se*), Cu, Pb		
Monongahela			Same as Scenario 2	
Susquehanna 0 (0)		-	-	-
Kanawha			Same as Scenario 2	
Ohio 6558 to 93833	25%	Cr, Ag, Cu*, Fe, Pb*, Mn, Hg		
59,006 (44,850)	10%	Cd, Zn	Zn*, B	SO_4, Cd, Cr, B, Cu*, Fe, Hg TDS, NH_3, Se*

EPA-287 (Cin.)
(4-70)

TABLE 7.12 (CONTINUED)

SCENARIO 3

River	Level of Significance	Constituents with significant concentration increases 0% Loading	5% Loading	100% Loading
Illinois 451 to 3601 cfs	25%	Fe, Mn,	B	TDS*, SO$_4$, NH$_3$, Cr*, Fe*, B*, Hg*
15,155 (2,600)	10%	Cu, Pb, Hg	Cr	Se, Cu
Big Muddy			Same as Scenario 2	
Rock			Same as Scenario 2	
Mississippi 15725 to 47412 cfs	25%	Hg, Fe*		Cr, B
15,721 (4,550)	10%	Mn		
White			Same as Scenario 2	
Wabash			Same as Scenario 2	
Big Sandy			Same as Scenario 2	
Green			Same as Scenario 2	
Kentucky			Same as Scenario 2	
Scioto 48 to 337 cfs	25%	Ag, Fe, Hg	Cr	B
90 (0)	10%	(TDS*), (Cd*), Cr, (Se*)		TDS*, SO$_4$, NH$_3$, Se*

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(4-76)

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TABLE 7.12 (CONTINUED)

SCENARIO 3

River	Level of Significance	Constituents with significant concentration increases 0% Loading	5% Loading	100% Loading
Muskingum			Same as Scenario 2	
Whitewater			Same as Scenario 2	
G. Miami			Same as Scenario 2	
L. Miami			Same as Scenario 2	
Beaver 86 to 232 cfs	25%	Fe, Mn, Hg		Cr, B
0 (650)	10%	(NH_3^*), Cr, (Se^*), (Pb^*) (Zn^*)		SO_4, NH_3^*, Se^*, Cu
Allegheny			Same as Scenario 5	
Monongahela			Same as Scenario 2	
Susquehanna			Same as Scenario 2	
Kanawha			Same as Scenario 2	
Ohio 6558 to 93833 cfs	25%	Cr, Ag, Cu^*, Fe, Pb^* Mn, Hg		Cu^*, Fe, Hg, B, Cr
59,006 (37,700)	10%	Cd, Zn	B	TDS, SO_4, NH_3, Se^*, Zn^*

EPA-287 (Cin.)
(4-76)

TABLE 7.12 (CONTINUED)

SCENARIO 4

River	Level of Significance	Constitutents with significant concentration increases 0% Loading	5% Loading	100% Loading
Illinois 451 to 3601 cfs	25%	Fe, Mn,		Cr^*, Fe, B^*, Hg
15,155 (650)	10%	Cu, Pb, Hg	Cr, B	TDS^*, SO_4, NH_3, Cu
Big Muddy			Same as Scenario 2	
Rock 0 (0)		-	-	-
Mississippi 15725 to 47412 cfs	25%	Hg, Fe^*		B
15,721 (1,300)	10%	Mn		Cr
White			Same as Scenario 2	
Wabash			Same as Scenario 2	
Big Sandy			Same as Scenario 2	
Green			Same as Scenario 2	
Kentucky			Same as Scenario 2	
Scioto			Same as Scenario 3	

EPA-287 (Cin.)
(4-76)

TABLE 7.12 (CONTINUED)

SCENARIO 4

River	Level of Significance	Constituents with significant concentration increases 0% Loading	5% Loading	100% Loading
Muskingum				
551 to 566 cfs	25%	Fe, Pb, Mn, Hg	Cr	Fe, Hg, B
1,826 (650)	10%	(TDS*), (Cd*), Cr, (Se*) Ag		TDS*, SO$_4$, NH$_3$(Cd*), Se*
Whitewater			Same as Scenario 2	
G. Miami			Same as Scenario 2	
L. Miami			Same as Scenario 2	
Beaver 0 (0)		-	-	-
Allegheny				
470 to 1098 cfs	25%	Fe, Mn, Hg	Cr	Fe, Hg, B
5,659 (650)	10%	Cr, (Se*)	B	TDS, SO$_4$, NH$_3$, Se*, Cu, Zn*
Monongahela			Same as Scenario 2	
Susquehanna 0 (0)		-	-	-
Kanawha			Same as Scenario 2	
Ohio				
6558 to 93833 cfs	25%	Cr, Ag, Cu*, Fe, Pb* Mn, Hg		Cr, Cu*, Fe, B, Hg
59,006 (20,800)	10%	TSS*, Cd		TDS, SO$_4$, NH$_3$, Se*, Zn*

EPA-287 (Cin.)
(4-76)

TABLE 7.12 (CONTINUED)

SCENARIO 1

River	Level of Significance	Constitutents with significant concentration increases 0% Loading	5% Loading	100% Loading
Illinois				
451 to 3601 cfs	25%	Fe, Mn,		SO_4, Cr*, Fe*, B*, Hg*
15,155 (1,950)	10%	Cu, Pb, Hg	Cr, B	TDS*, NH_3, Cu
Big Muddy			Same as Scenario 2	
Rock			Same as Scenario 2	
Mississippi	25%	Hg, Fe*		Cr, B
	10%	Mn		
White				
155 to 685 cfs	25%	Fe, Hg		SO_4, Cr*, B
1,535 (1,950)	10%	Mn	Cr*, B	TDS, NH_3, Cd*, Se, Cu
Wabash				
130 to 2498 cfs	25%	Fe, Hg		SO_4, NH_3, Cr, Se, Fe, Hg, B
6,932 (5,850)	10%		Cr, B	TDS*, (Cd*), Cu, Zn
Big Sandy				
26 to 59 cfs	25%	Cr, Se*, Cu, Fe, Pb, Mn Hg, Zn	Cr, B	TDS*, SO_4, NH_3*, As, Cd, Se*, Ag Cu, Fe, Hg, Zn
0 (650)	10%	TDS, SO_4, Cd, Ag	NH_3	Cl
Green			Same as Scenario 2	
Kentucky			Same as Scenario 2	
Scioto			Same as Scenario 2	

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PAGE NUMBER

EPA-287 (Cin.)
(4-76)

TABLE 7.12 (CONTINUED)

SCENARIO 1

River	Level of Significance	Constituents with significant concentration increases 0% Loading	5% Loading	100% Loading
Muskingum 551 to 566 cfs	25%	Fe, Pb, Mn, Hg		Cr, Fe, B, Hg
1,826 (0)	10%	(TDS^*), (Cd^*) Cr, (Se^*) Ag		SO_4, NH_3, (Cd^*), Se^*, (TDS^*)
Whitewater 82 cfs	25%			TDS, SO_4, NH_3, Cr, $\hat{Se}$, Fe, Hg, B
160 (650)	10%		$\hat{Cr}$, $\hat{Fe}$, $\hat{Hg}$, B	Cu, Zn
G. Miami 58 to 281 cfs	25%	Fe, Hg		B, Cr
160 (650)	10%	Cr, Mn		Zn, SO_4, NH_3, Se^*
L. Miami 27 cfs	25%	TDS^*, Cd, Cr, Se, Cu, Fe Pb, Mn, Hg	B	TDS^*, SO_4, NH_3^*, As, Se^*, Ag, Cu, Fe, Hg, Zn^*
0 (650)	10%	NH_3, Zn	$\hat{SO}_4$	Cl
Beaver 0 (0)		-	-	-
Allegheny 470 to 1098 cfs	25%	TDS, As, Cr, Cu^*, Fe, Pb Mn, Hg	B	TDS, SO_4^*, NH_3^*, As, Cl, Se^*, Ag Cu^*, Fe, Hg, Zn^*
5,659 (7,150)	10%	Se^*, Zn^*	$\hat{SO}_4$, $\hat{NH}_3$	Cd
Monongahela 384 to 459 cfs	25%	Cr, Fe, Mn, Hg, Zn		TDS, SO_4^*, NH_3, Se^*, Cu, B
2,470 (1,950)	10%	Se^*, Pb^*	$\hat{Cd}$, B	As
Susquehanna			Same as Scenario 2	
Kanawha 1106 to 1284 cfs	25%	Fe, Hg		Cr, B
2,931 (650)	10%	(Cd^*), (Se^*), Pb^*, Mn	$\hat{Cr}$	Se^*, SO_4, NH_3,
Ohio 6558 to 93833 cfs	25%	Cr, Ag, Cu^*, Fe, Pb^*, Mn, Hg		Cr, Cu^*, Fe, Hg, B
59,006 (46,800)	10%	Cd	B	TDS, SO_4, NH_3, Se^*, Zn^*

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TABLE 7.12 FOOTNOTES

37 *indicates new violations of the reference standard.
^indicates that although the constituent is listed in the 5% loading category, approximately half (or more) of the effect results from plant consumption.
( )indicates that the increase of concentration is less than 10% of the reference standard, but that it still causes a new violation.
38 Range of values of the 7-day 10-year low-flow in the various river reaches (cfs).
39 a(b) = a is the planned capacity (MW)
b is the conjured capacity (MW).

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

considered; these two cases highlight the fact that the major effects often result from plant consumption. Key observations are given in Section 7.6.

7.5.3 Water Quality Analysis of Each Scenario

Based on the screening process described above, the potential impacts are summarized in Table 7.12. The screening process was based on many assumptions, and the potential increases in concentration that are listed should be viewed as upper bounds and not projections. Potential impacts for each river under each scenario are discussed below.

7.5.3.1 Scenario 2

This scenario includes 74,727 MW of planned plant capacity and 61,750 MW of conjured coal-fired plant capacity. The analysis of each river basin is given below:

Illinois. Under 15,155 MW and 5,200 MW of planned and conjured plant capacities, respectively, the power consumption would represent most of the projected consumption. The highest power consumption ratio, however, would be only 8%. The significant estimated increases in Fe, Mn, Hg, Cu, and Pb attributed to plant consumption result from high background concentrations in some reaches. Significant increases in Cr and B would result mainly from plant loadings. No new violations of the reference standards were calculated.

Big Muddy. The impacts are the same for all scenarios and are attributed to 346 MW of planned plant capacity. Since the 7-day 10-year low flow is relatively small, 37 cfs, there may be some minor impacts. The background TDS (484 mg/l) is high and very small increases may lead to violations of the reference standard (500 mg/l). The calculated increase resulting from plant consumption alone, however, would not be enough to cuase a new violation; the major effect would result from projected M & I water consumption. As shown in Table 7.12, there would be small increases (at a level over 10% of the reference standard) in the concentrations of Cr, Fe, Hg, and B under the 5% loadings, but there would be no potential violations.

Rock. All scenarios specify 1300 MW of conjured coal plants (except for Scenario 4 which specifies no plants). The Rock has a relatively large 7-day 10-year low flow (1306 cfs), and as a result the potential impacts of plants on water quality parameters appear small. The effect of plant consumption (13 cfs) is negligible, and there were no parameters with significant increases in concentrations under 5% loadings.

Mississippi. Above the confluence of the Mississippi and Ohio Rivers, there are 15,721 MW of planned capacity and 7,800 MW of conjured plant capacity. The 7-day 10-year low-flow ranges from 15,725 cfs to 47,412 cfs. Since the maximum total consumption is 2%, power plant impacts on water quality are negligible.

Below the confluence with the Ohio River, the increases in the concentrations of Hg, Fe, and Mn would exceed either 10% or 25% of their reference standards although the power consumption ratio is less than 2%. These increases result from very high background levels and represent negligible incremental effects.

EPA-287 (Cin.)
(4-76)

White. In this scenario, there are only 1,535 MW of planned plant capacity. Because of high background concentrations of Fe and Hg the maximum increases in their concentrations would be greater than 10% of the reference standard. The impact on water quality would be small, however, since the maximum consumption by power plants alone is only 3% of the 7-day 10-year low-flow.

Wabash. Under 6,932 MW and 2,600 MW of planned and conjured capacities, respectively, there are substantial increases in Fe and Hg concentrations resulting from plant consumption. Each of these parameters has a high background concentration which greatly exceeds the reference standard. When 5% loadings are taken into account, the increases in Cr and B exceed 10% of the reference standards; this effect results from plant loadings alone since background concentrations are not available for these constituents.

Big Sandy. Under this scenario no plants are specified for the Big Sandy.

Green. Under each scenario there are only 480 MW of planned plant capacity. The background concentrations of Mn and Fe greatly exceed the reference standards (see Tables 7.1 and 7.10), and those concentrations would be increased by plant consumption.

Kentucky. Under each scenario there are only 440 MW of planned plant capacity. Background concentration were not used in the analysis, but the effect of plant consumption (4 cfs) should be insignificant since stream flows are between 113 cfs and 164 cfs during low flow conditions. The 5% plant loadings also would produce no significant impacts.

Scioto. Under 90 MW and 1,300 MW of planned and conjured capacities, respectively, there are several impacts that would result from plant consumption since the 7-day 10-year low flow ranges from 48 cfs to 337 cfs. Two new violations are listed for TDS, but they would result from projected M & I consumption alone given background concentrations that are nearly as large as the reference standard. The largest increase in background concentration from plant consumption alone is only 17 mg/l. The concentrations of several metals would increase substantially as a result of plant consumption. Most of those metals have high background concentrations that exceed the reference standard in some reaches; there would be new violations only for Cd and Se. These violations would occur as a result of projected M & I consumption (the highest estimated M & I consumption ratio is 45%) and because of high background concentrations.

Muskingum. Under 1,826 MW and 1,950 MW of planned and conjured plant capacities, respectively, there would be some increases in background concentrations as a result of plant consumption even though the highest power consumption ratio is only 7%. New violations would occur in both reaches for TDS because of plant consumption although the actual increase resulting from plant consumption alone would be only 33 mg/l. The background levels are close to the 500 mg/l reference standard. There would also be significant increases in the concentrations of several metals (see Table 7.12)—primarily because of high background concentrations. The new violations listed for Cd and Se would result from projected M & I consumption alone, however. Under

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

5% loadings there would be an increase in the B concentration that exceeds 10% of the reference standard.

Whitewater. The Whitewater has only 160 MW of planned plant capacity and there appear to be no significant impacts resulting from consumption (2 cfs) or 5% loadings. Background concentrations were considered only for TDS, TSS, and NH_3.

Great Miami. Under 160 MW of planned capacity there would be a significant increase in the concentrations of Fe resulting from plant consumption because of a very high background concentration.

Little Miami. Under this scenario no plants are specified for the Little Miami.

Beaver. Under 1,950 of conjured plant capacity, there would be significant increases in the concentrations of several metals and NH_3 resulting from plant comsumption as well as from projected M & I consumption. Many of the increases are significant because of high background concentrations (e.g., for Cr, Ag, Cu, Fe, Mn, and Hg). There would be new violations of Cu, Cd, Se, Pb, Zn, and NH_3; the new violations of Se, pb, Zn, and NH_3, however, would also occur under M & I consumption alone. Note that the increase in Cd is small (less than 10% of the reference standard). Also, the actual impact on NH_3 would be less than indicated because that constituent is not conservative. Under 5% loadings, the increase in B would exceed 10% of the reference standard.

Allegheny. Under 5,659 MW and 4,550 MW of planned and conjured plant capacities, respectively, the consumption resulting from power plants would lead to significant increases in TDS and eight metals. Note that most of the projected consumption is associated with power development. The largest increase in the TDS concentrations would be 108 mg/l if plant consumption alone is taken into account. If loadings from the plants are considered, there would also be a significant increase in the B concentration.

Monongahela. Under 2,470 MW and 1,950 MW of planned and conjured plant capacities, respectively, the power-related consumption is approximately half of the total projected consumption. The concentrations of seven metals, which have high background levels, would increase significantly. New violation (Se and Pb) would occur only where background concentrations were equal to the reference standard. Increases in the concentrations of Cd and B would also be greater than 10% of the reference standard when plant loadings are also considered.

Susquehanna. Under only 650 MW of conjured plant capacity, the consumptive effect (7 cfs) would be small relative to the low flow (136 cfs). Although background concentrations were not considered, it can be estimated that the impacts would be insignificant. (Note that the Susquehanna River is not in the Ohio River Basin.)

Kanawha. Under 2,931 MW of planned capacity, most of the projected consumption results from M & I uses. The metals listed in Table 7.12 have high background concentrations which would increase significantly relative to

EPA-287 (Cin.)
(4-76)

the reference standard; new violations would occur in cases where the background levels equal or nearly equal the standard.

Ohio. Under the assumption that the consumptive impacts and plant loadings of the planned plants (59,006 MW) and conjured plants (53,300 MW) in the Ohio Basin carry through to the main stem, most of the effects would result from plant consumption, which represents approximately 60% of the total projected consumption. The power-related consumption ratios are generally from 5% to 7% of the 7-day 10-year low flow values. As a result the increases in the concentration levels would typically be from 5.3% to 7.5% of the background levels. Because the background levels of Cd, Cr, Ag, Cu, Fe, Pb, Mn, and Hg are much greater than their reference standards, however, the increase would exceed 25% of those standards. One new violation of the reference standard for Cu would occur in a reach where the background level is nearly equal to that standard, and M & I consumption alone would cause the violation. (The increases in the concentration of Cu that exceed 25% of the reference standard occur in other reaches.) There would also be new violations of the reference standard (.05 mg/l) for Pb in 4 reaches (with background levels of .05, .049, .045 and .045 mg/l); M & I consumption alone would cause only two of these violations. There would be two new violations of the reference standard for Zn, and they would not be caused by M & I consumption alone. The 5% plant loadings would not increase the concentrations significantly, except in the case of B. The TDS concentration would increase only 26 mg/l because of plant consumption and only 32 mg/l when 5% plant loadings are also considered. (See also Section 7.5.3.3 for additonal discussion.)

7.5.3.2 Scenario 2a

This scenario is identical to Scenario 2 with respect to all rivers except those cases discussed below. Each case includes additional conjured coal-fired plant capacity.

Mississippi. Under Scenario 2a, the potential impacts above the confluence with the Ohio River would be identical to those under Scenario 2. Below the confluence the impacts are also very similar; the increase in the concentration of Ag is slightly greater and is significant at the 10% level.

Scioto. The impacts of Scenario 2a are similar to those of Scenario 2 except that the effects of power plant consumption would be greater because of the additional 1,300 MW of conjured capacity. There are significant increases in the concentrations of numerous metals with high background concentrations. When plant loadings are taken into account, there would be significant increases in the concentrations of B.

Muskingham. The impacts are similar to those of Scenario 2 except that the effects of power plant consumption are greater because of the additional 1,300 MW of conjured capacity. There would be significant increases in the concentrations of metal with high background levels; there would also be some impacts associated with discharges of B.

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EPA-287 (Cin.)
(4-76)

Beaver. This scenario has 650 MW of total plant capacity in addition to that of Scenario 2. The impacts are similar, although somewhat greater. The TDS concentration would increase 29 mg/l because of plant consumption alone. Given projected M & I consumption, the effect of power consumption and TDS loading would be an increase of 58.5 mg/l.

Allegheny. This scenario has 2,600 MW of capacity in addition to that of Scenario 2. As in Scenario 2, there would be impacts on the concentrations of numerous metals and TDS because of plant consumption. The maximum increase in TDS due to consumption alone would be 108 mg/l (the same as in Scenario 2).

Ohio. Under Scenario 2a there are 73,450 MW of conjured coal-fired plant capacity in addition to the 59,006 MW of planned capacity. The conjured capacity under Scenario 2 is 53,300 MW. The impacts under Scenario 2a are similar to those under Scenario 2 although somewhat greater. For example, there would be two new violations of the reference standard for Cu that would not occur as a result M & I consumption alone. There would also be one additional violation of the reference standard for Zn. When 5% plant loadings are considered, there would be significant increases in the level of Se as well as B. (See Section 7.5.3.3 for additional discussion.)

7.5.3.3 Scenario 2b

This scenario is identical to Scenario 2 except for the cases discussed below. Each of these cases includes additional conjured nuclear plant capacity.

Illinois. The only difference between this scenario and Scenario 2 is that an additional 1,000 MW of nuclear capacity are included. The potential impacts are roughly the same.

Mississippi. Scenario 2b specifies an additional 1,000 MW of nuclear plant capacity above the confluence with the Ohio River in comparison to Scenario 2. The incremental impact of loading and consumption by the additional 1,000 MW is negligible, as discussed for Scenario 2.

Below the confluence the impacts are similar to those of Scenario 2; the increases in the concentrations of Ag and Pb are slightly greater and are significant at the 10% level. Nevertheless, the actual incremental impact is insignificant.

Allegheny. In comparison to Scenario 2, 4,000 MW of nuclear capacity are added. Zn is added to the list of metals with significant increases, and there would be new violations of the reference standard for that constitutent as a result of plant consumption. There would also be greater impacts for the other constituents in comparison with Scenario 2.

Monongahela. In comparison to Scenario 2, 2,000 MW of nuclear capacity are added. Because of high levels of consumption (17% and 30% for power consumption and M & I consumption, respectively, in the highest reach), the increases in concentrations of numerous constitutents would be even greater than under Scenario 2. Additional constituents with significant increases are TDS, SO_4, NH_3, Cd, and Cu.

Ohio. Scenario 2b has 72,300 MW of conjured plant capacity in addition to the planned capacity. In comparison, Scenario 2 has less conjured capacity, 53,300 MW, and Scenario 2a has slightly greater conjured capacity, 73,450 MW of coal-fired plants. The consumptive impacts are greater under Scenario 2b than under Scenario 2a because the cooling requirements of nuclear plants are greater than those of coal-fired plants. Plant loadings are greater under Scenario 2a. Since the greatest estimated impacts result from consumptive effects, Scenario 2b has slightly greater impacts than any other scenario.

The estimated upper bounds on the concentration increases for 10 metals are listed in Table 7.13. These estimates do not take M & I consumption into account; each effect would be somewhat greater if it were. The M & I effect is not very significant, however, since the projected M & I consumption ratio does not exceed 5% of the 7-day 10-year low flow in any reach.

Table 7.13 demonstrates the observation that the impacts of Scenario 2b are larger than those of the other scenarios. The estimated maximum increase in the concentration of Cu, for example, is 0.038 mg/l under scenario 2b. Note that the consumptive impact is the major effect; the increase is 0.038 mg/l (rounded to two significant figures) whether 5% plant loadings are considered or not. Under Scenario 2a the increase would be less; 0.034 mg/l if 5% plant loadings are also taken into account. As another comparison, the impacts of Scenario 4, which specifies the least total plant capacity, tend to be much less.

Although the impacts of Scenario 2b are somewhat greater than under Scenario 2, they are similar in character (see discussion of Scenario 2). One additional metal, Se, would increase in concentration more than 10% of the reference standard.

7.5.3.4 Scenario 5

This scenario is identical to Scenario 2 except for the cases discussed below. Each of these cases has less conjured coal-fired plant capacity than under Scenario 2 but more than under Scenario 3.

Illinois. This scenario has 3,250 MW of conjured plant capacity (as well as 15,155 MW of planned capacity) in comparison to 5,200 MW and 2,600 MW under Scenarios 2 and 3, respectively. As in those scenarios, the consumption ratios are low and significant increases because of plant consumption result from high background concentrations. Also, there would be significant increases in Cr and B when plant loadings are taken into account.

Mississippi. Scenario 5 specifies 5,850 MW of conjured plant capacity above the confluence with the Ohio River—1,950 MW less than under Scenario 2. Water quality impacts are negligible as discussed for Scenario 2. Below the confluence the impacts are nearly the same as under Scenario 2 and are insignificant.

Scioto. Under this scenario there are 90 MW of planned and 650 MW of conjured plant capacities, respectively. In comparison, Scenarios 2 and 3 have 1,300 MW and no MW, respectively, of conjured capacity. The impacts are less for

TABLE 7.13 COMPARISON OF POTENTIAL CONCENTRATION INCREASES OF TEN METALS UNDER FOUR SCENARIOS

Constituent	Max Bkgd Conc. (mg/l)	Ref. Std. (mg/l)	Maximum Increase in Concentration (mg/l)											
			Plant Consumption				Plant Consumption and 5% loading				Plant Consumption and 100% loading			
			2	2b	2a	4	2	2b	2a	4	2	2b	2a	4
Cd	.044	.01	.002	.004	.003	.002	.002	.004	.003	.002	.003	.004	.003	.002
Cr	.14	.01	.006	.009	.007	.004	.006	.01	.007	.004	.024	.03	.029	.017
Ag	.003	.005	.002	.003	.003	.002	.002	.003	.003	.002	.002	.003	.003	.002
Cu	.4	.06	.026	.038	.033	.018	.026	.038	.034	.018	.03	.043	.04	.021
Fe	20.5	.3	1.38	2.0	1.7	1.0	1.40	2.0	1.8	1.0	1.9	2.5	2.3	1.4
Pb	.89	.05	.046	.068	.059	.029	.046	.068	.059	.029	.046	.068	.059	.029
Mn	3.8	.05	.237	.35	.309	.162	.237	.35	.309	.162	.24	.35	.309	.16
Hg	.0024	.05	.10	.15	.116	.069	.10	.16	.118	.07	.14	.19	.16	.092
Se	<.01	.01	.001	.001	.001	.001	.001	.001	.001	.001	.002	.003	.003	.002
Zn	.4	.205	.022	.032	.028	.015	.022	.033	.029	.015	.032	.043	.041	.021

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

most constitutents listed than under Scenario 2. The constituents with significant increases are the same as under Scenario 2 with the exception of Pb.

Allegheny. The conjured plant capacity is 1,300 MW less than under Scenario 2, which specifies a total capacity of 10,209 MW. The impacts are only slightly less than under Scenario 2, although for some constituents the reaches with the greatest impacts remain unchanged because changes in plant capacities occur downstream.

Susquehanna. There are no plants located on the Susquehanna under this scenario.

Ohio. Scenario 5 specifies 44,850 MW of conjured plant capacity in comparison to 53,300 MW of conjured capacity under Scenario 2. Although somewhat less in magnitude, the significant increases listed in Table 7.12 are similar to those of Scenario 2 and result mainly from power-related consumption in reaches with high background levels.

7.5.3.5 Scenario 3

This scenario is identical to Scenario 2 except for the cases discussed below. Each of these cases has less conjured coal-fired plant capacity than under Scenario 2 and less than under Scenario 5.

Illinois. This scenario has 2,600 MW of conjured plant capacity compared to twice that amount for Scenario 2. As in Scenario 2, the consumption ratios are low and significant increases in the concentrations of several metals because of plant consumption would result from high background concentrations. Significant increases in Cr and B would result from plant loadings although the levels of the increases would be lower than those under Scenario 2.

Mississippi. Scenario 3 specifies 4,550 MW of conjured plant capacity above the confluence with the Ohio River—3,250 MW less than under Scenario 2. The water quality impacts are negligible as discussed for Scenario 2. Below the confluence, the impacts are similar to those under Scenario 2 and are insignificant.

Scioto. Under this scenario, only 90 MW of planned capacity are located on the Scioto. The significant increases shown in Table 7.12 result from very high background concentrations relative to the reference standard.

Beaver. Under 650 MW of conjured plant capacity (in comparison to 1,950 MW under Scenario 2), the impacts would be less than under Scenario 2. There are fewer constituents with significant increases, and the levels of the increases are less. Most significant increases result from high background concentrations. The new violations would occur as a result of projected M & I consumption alone.

Allegheny. The impacts under this scenario are identical to those discussed above for Scenario 5.

EPA-287 (Cin.)
(4-76)

Ohio. Scenario 3 specifies 37,700 MW of conjured plant capacity in comparison to 53,300 MW of conjured capacity under Scenario 2. Although somewhat less in magnitude, the significant increases listed in Table 7.12 for Scenario 3 are similar to those of Scenario 2 and result mainly from power-related consumption in reaches with high background concentrations. Significant increases would also occur for B when 5% plant loadings are taken into account.

7.5.3.6 Scenario 4

This scenario specifies the lowest total power plant capacity, but it is identical to Scenario 2 for many rivers. Each of the rivers discussed below contains less plant capacity than Scenario 2—and less than or equal to the capacities under Scenario 3 (and Scenario 5).

Illinois. This scenario has 650 MW of conjured plant capacity; in comparison, Scenario 2 has 5,200 MW. The potential impacts on all constituents are less than under Scenario 2, but the increases in the concentrations of several constituents are still significant. The impacts resulting from power plant consumption reflect high background concentrations. The increases in Cr and B, which become significant with 5% plant loadings, are less severe in this scenario.

Mississippi. Scenario 4 specifies 1,300 MW of conjured plant capacity above the confluence with the Ohio River—6,500 MW less than under Scenario 2. Water quality impacts are negligible as discussed for Scenario 2. Below the confluence the impacts are similar to those under Scenario 2 and are insignificant.

Rock. There are no plants located on the Rock under this scenario, and therefore, there would be no impacts.

Scioto. The impacts are the same as those discussed above for Scenario 3.

Muskingham. This scenario specifies 650 MW of conjured capacity in addition to 1,826 MW of planned capacity. Scenario 2 specifies 1,950 MW of conjured capacity in addition to the planned capacity. The effects of plant consumption are less, but there are still significant increases in the concentrations of several constituents because of high background levels. There would be a new violation of the TDS reference standard in one reach because of plant consumption. The conditions discussed under Scenario 2 also apply to Scenario 4.

Beaver. Under this scenario no plants are located on the Beaver River, and therefore, there are no impacts.

Allegheny. Under 5,659 MW and 650 MW of planned and conjured capacities, respectively, the consumptive impacts are less than under Scenario 2, which specifies 4,550 MW of conjured capacity in addition to the planned capacity. For example, the increases in the TDS, Cu, As, and Pb concentrations are not significant (at the 10% level) as they were under Scenario 2.

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

Susquehanna. Under this scenario there are no plants, and therefore no impacts.

Ohio. With 20,800 MW of conjured capacity and 59,006 MW planned capacity, this scenario has the least capacity of all the scenarios. In comparison, Scenario 2 has 53,500 MW of conjured capacity as well as the planned capacity. The impacts are similar to those of Scenario 2 although somewhat smaller in magnitude. As examples, the maximum increases in the concentrations of Cd is significant at the 10% level instead of at the 25% level as in Scenario 2. The increase in the concentration of Zn is not significant in Scenario 4. Additional comparisons can be observed in Table 7.13. In general, the significant increases result from plant consumption in reaches with high background levels. (See additional discussion in Sections 7.5.3.1 and 7.5.3.3.)

7.5.3.7 Scenario 1

This scenario specifies a total of 61,750 MW (95 coal-fired plants), but the water requirements of 9,750 MW (15 plants) were assumed to be met by storage since there were no rivers of sufficient size nearby (see Section 6.4.1). The 52,000 MW that were assumed to affect river flows were dispersed much more than under the previously discussed scenarios. As a result, several small rivers would have impacts that would not occur under the other scenarios, and some rivers would have greater impacts. All rivers with impacts different from those under Scenario 2 are discussed below.

Illinois. This scenario has only 1,950 MW of conjured plant capacity in comparison to 5,200 MW under Scenario 2. Because the planned capacity, however, is 15,155 MW, the potential water quality impacts would not be significantly different. The increases in the concentrations of pollutants would be somewhat lower.

Mississippi. Above the confluence with the Ohio River, Scenario 1 and Scenario 3 specify identical power plant sites along the Mississippi River. Water quality impacts are negligible as discussed for Scenario 2. Below the confluence, the impacts are similar to those under Scenario 2 and are insignificant.

White. Scenari 1 specifies 1,950 MW of conjured plant capacity in addition to the 1,535 MW of planned plant capacity under Scenario 2. The maximum incremental concentrations of Fe and Hg increase from the 10% level observed in Scenario 2 to the 25% level in Scenario 1. In addition, incremental concentrations of Mn are significant at the 10% level. Under 5% plant loadings, maximum incremental concentrations of Cr and B are 10% of the reference standard.

Wabash. Under 6,932 MW of planned plant capacity and 5,850 MW of conjured capacity, the consumptive impacts would be somewhat greater than under Scenario 2, which specifies 2,600 MW of conjured capacity in addition to planned capacity. The constituents that would increase significantly in concentration, however, are the same. The estimated increase in the Fe concentration resulting from plant consumption alone is .12 mg/1 under Scenario 1 in comparison to .08 mg/1 under Scenario 2.

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EPA-287 (Cin.)
(4-76)

Big Sandy. This scenario is the only one that specifies plant capacity for the Big Sandy. The 650 MW plant specified for this river would consume approximately 25% of the low flow in the first reach (the 7-day 10-year low flows are 26 cfs and 59 cfs on the two reaches). There would be significant increases in the concentrations of numerous constituents. All of the increases that exceed 25% of the reference standard because of consumption occur in cases where the background concentration is high (equal to or greater than the reference standard). The only new violation would be in the case of Se, and it also has a high background concentration. The increase in the concentration of Se would be .004 mg/l because of plant consumption and plant loading; the reference standard is .01 mg/l. The increase in the concentration of TDS would be 83 mg/l as a result of plant consumption and loading. When plant loadings are considered, there are also significant increases in B, Cr, and NH_3.

Muskingum. Under only 1,826 MW of planned capacity, the impacts are less significant than under Scenario 2, which specifies 1,950 MW of conjured capacity as well as the planned capacity. Significant increases and new violations, however, are listed for the same parameters, and the conditions discussed under Scenario 2 apply to Scenario 1 as well.

Whitewater. Under Scenario 1, the Whitewater has 650 MW of conjured capacity as well as the 160 MW of planned capacity. All other scenarios specify only the 160 MW of planned capacity. Plant loadings would lead to significant increases in the concentrations of Cr, Fe, Hg, and B; the increases in background concentrations because of plant consumption were not estimated because background levels were not available.

Great Miami. Under Scenario 1, there are 650 MW of conjured capacity as well as the 160 MW of planned capacity; all other scenarios specified only the planned capacity. Under Scenario 1, there would be greater increases in the concentrations of Fe, Mn, Hg, and Cr than in the other scenarios. The maximum power-related consumption ratio is only 3%. those metals with significant increases have high background levels.

Little Miami. Scenario 1 is the only scenario with any plant capacity on the Little Miami; 650 MW of conjured capacity are specified. The power consumption ratio is 24% since the low flow is only 27 cfs, and there are many significant increases in concentration levels. The background level of TDS is 387 mg/l and the estimated increase would be 135 mg/l as a result of consumption alone, leading to a new violation of the reference standard (500 mg/l). Many of the metals that would increase significantly have high background levels.

Beaver. There are no power plants planned or conjured for the Beaver River.

Allegheny. Scenario 1 specifies 7,150 MW of conjured capacity which is 2,600 more than Scenario 2. The maximum consumption by power plants is 35% of the 7-day 10-year low-flow in comparison to 12% computed for Scenario 2. Since background concentrations are high for most constituents, the higher

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

consumption rate alone causes more severe water quality impacts than indicated for Scenario 2. For example, the maximum incremental concentrations of TDS, As, and Pb increase from 10% (Scenario 2) to 50% (Scenario 1) of their respective reference standards. Under 5% loadings, additional impacts of SO_4, NH_3, and B were significant.

Monongahela. Scenario 1 specifies 650 MW of conjured capacity for each reach of this three-reach river. In comparison, Scenario 2 specifies the same amount of total conjured capacity, 1,950 MW, but it is all sited in the last reach. Since the last reach has the highest total consumption (23% of 7-day 10-year low-flow) and high background concentrations, the maximum incremental impacts for these two scenarios are identical. See the discussion of Scenario 2 for further details.

Kanawha. Under Scenario 1, 650 MW of conjured capacity are added to the 2,931 MW of planned capacity considered in Scenario 2 (and in all other scenarios). The power-related consumption ratio increases slightly and the increases in the concentrations of several metals with high background levels would be greater than under Scenario 2.

Ohio. Under Scenario 1, 46,800 MW of conjured capacity as well as the planned capacity were considered in the analysis. The impacts of an additional 15 plants with 650 MW capacity each were not considered since it was assumed that they would not be located on major rivers. In comparison, Scenario 2 specifies 53,300 MW in addition to the planned capacity. The impacts under Scenario 1 are similar to those under the other scenarios in that the major effects result from plant consumption in reaches with high background levels. The impacts are somewhat less than under Scenario 2. Specifically, the increase in the concentration of Cd would be significant at the 10% level rather than at 25% of the reference standard, and the increase for Zn would not be significant at the 10% level.

7.5.3.8 Scenarios 2i, 2a2, and 2b1 (Once-Through Cooling)

These scenarios are identical to Scenarios 2, 2a, and 2b, respectively, except that they specify once-through cooling for conjured plants on the Rock, Illinois, Ohio, and Mississippi Rivers. As discussed in Sections 6.6, 6.8, and 6.10, the differences in total consumption between the two sets of Scenarios are quite small (typically on the order of 1% or less of the 7-day 10-year low flow). As a result the potential impacts on water quality from consumption are not significantly different. The only plant loadings that would be changed are those for TDS and SO_4 (see Section 7.3.8). When 100% plant loadings for these constituents are considered, there would be reductions in their ambient concentrations if once-through cooling were substituted for cooling towers. Specifically, in Table 7.12 SO_4 would not appear under the 100% loading column for the Ohio River. (See also Section 7.6, where the effects on TDS and SO_4 under 100% loadings would be decreased with greater use of once-through cooling.)

EPA-287 (Cin.)
(4-76)

7.6 OVERVIEW

The preceeding section discusses the results of the screening process to determine potential impacts under 0% and 5% plant loadings. The key observations are:

1. Plant consumption would lead to many cases where the concentration of a constituent would increase 10% or 25% of the reference standards. In most such cases, however, the consumption ratio is a small percentage of the 7-day 10-year low flow, and the increase in the concentration is large relative to the reference standard because the background concentration is very high. In such cases, the actual incremental effect would not be very significant. For example, under Scenario 2 the power-related consumption ratios for the Ohio River are generally from 5% to 7% of the 7-day 10-year low flow values, and the resulting increases in concentration levels of constituents would only be from 5.3% to 7.5% of the background levels. Although the actual incremental impacts may be insignificant, the increases in the concentration levels of some metals would exceed 25% of the corresponding reference standards because the background levels greatly exceed those standards. There would, of course, be some exacerbation of existing water quality problems (see Section 7.2); as an example, Table 7.6 lists several metals (e.g., Pb, Fe, and Hg) as water quality problems in the Ohio River.

   In some cases, however, significant increases in the concentrations of constituents also result from high consumption ratios, especially under Scenario 1 which specifies dispersed plant locations. As examples, there would be significant increases in the concentrations of numerous metals and total dissolved solids in the Big Sandy and Little Miami Rivers which are small tributaries with consumption ratios of approximately 25%. There would be a new violation of the total dissolved solids standard in the Little Miami. It is important to recognize, however, that these potential impacts would be elimated if minor changes were made in the plant siting configuration; the few plants located under Scenario 1 in regions without major rivers could be relocated. Alternatively, water storage could be provided although there would most likely be other social and environmental impacts.

2. The 5% plant loadings cases would generally produce insignificant additional impacts in comparison to the impacts resulting from plant consumption alone (as shown in the 0% plant-loading case). Very few impacts are listed in Table 7.12 in the 5% loading column, which lists only the cases where the concentration increases would be significant under the 5% plant loadings but not significant because of plant consumption alone. It is possible that the increase in the concentration of a given constituent would exceed 10% of the reference standard because of plant consumption alone and would also increase a comparable amount because of plant loadings alone. In such cases that constituent would be listed in the 0% loading column but not the 5% loading column. It would be inappropriate, however, to conclude

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EPA-287 (Cin.)
(4-76)

that the 5% plant loadings would have a relatively insignificant impact. This situation, however, does not usually occur; for one illustration refer to Table 7.13 which illustrates the typical dominating effect of plant consumption relative to 5% plant loadings.

The only major exception is for Boron; if the assumed plant discharge is correct, there could be significant increases in the concentration of that constituent. (In addition, after carrying out the analysis it was learned that Boron may also be discharged from the ash ponds of coal-fired plants--at nearly one half of the rate listed under boiler blowdown in Table 7.8 (30).) No potential new violations were listed, but background levels were available only for rivers in Illinois. Occasionally, increases in the concentrations of some metals (e.g., Cr) would also become significant when plant loadings were taken into account.

3. Some new violations of the reference standards would occur, as summarized in Table 7.14. Most of the new violations would also result from projected M & I consumption alone, however, as indicated by asterisks. The absence of an asterisk indicates that in at least one reach a new violation would not occur as a result of M & I consumption alone but would occur if plant consumption and 5% loadings are taken into account. Many new violations would occur in reaches where the background level is very close to the standard. (Also see discussion above and Table 7.12.)

Table 7.12 also includes a column for 100% plant loadings. (Such loadings are not expected in the future because of new source discharge regulations and because of current design practices.) It can be noted, however, that under such high discharge levels, there would be significant increases in many constituent levels in many cases as well as numerous new violations.

Of all discharge streams, it is most likely that cooling tower effluents would be as large as indicated in Table 7.9. For example, H_2SO_4 may be used for pH control to prevent scaling. One result would be discharges of SO_4, which represents one component of TDS. Thus, an additional series of analyses was carried out. It was assumed that all plant loadings would be at the 5% level except that the SO_4 and TDS loadings associated with cooling tower blowdown would be at the 100% level.

The results of these analyses indicate that there would be numerous significant increases in the concentrations of SO_4 and TDS as shown in Table 7.15. The table lists only the significant increases that would not occur in the 5% loading case discussed in the preceeding section. New violations of the reference standard for TDS and SO_4 are also indicated only for cases for which new violations were not noted in Table 7.12 for the 0% and 5% loading cases. Such new violations of the TDS reference standard would occur only for the Illinois River (in Scenarios 2, 2a, 2b, 5 and 3). The new violations for SO_4 would occur for the Big Muddy (all scenarios are identical), and for the Big Sandy and Allegheny under Scenario 1.

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 7.14 SUMMARY OF NEW VIOLATIONS OF REFERENCE STANDARDS

River	Scenario	Constituents with new violations
Big Muddy	all	TDS*(41)
White	all	CR*, Cd*
Wabash	all	Cd*
Big Sandy	1	Se*
Scioto	all	TDS*, Cd*, Se*
Muskingum	all	TDS
	all	Cd*, Se*
Great Miami	all	Cu*, Cd*, Se*
Little Miami	1	TDS, Se
Beaver	2, 2a, 2b, 5	Cu, Cd, Se, NH$_3^{*}$, Pb*, Zn*
	3	NH$_3^{*}$, Se*, Pb*, Zn*
Allegheny	2, 3, 4, 5	Se*
	2a, 2b	Zn, Se*
	1	Cu, Zn, Se*
Monongahella	2, 2a, 5, 3, 4	Se*, Pb*
	1	Se*, Pb
	2b	Se*, Pb*, Cd*
Kanawha	all	Pb*, Cd*, Se*
Ohio	2,5	Se*, Cu*, Pb, Zn
	2b	Se, Cu, Pb, Zn
	2a	Se*, Cu, Pb, Zn
	3, 1	Cu*, Se*, Pb
	4	Cu, Se, Pb

[41] An asterisk indicates that consumption from M & I alone would cause a new violation.

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EPA-287 (Cin.)
(4-76)

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TABLE 7.15 INCREASE OF TDS AND SO_4 CONCENTRATIONS UNDER 100% LOADING ASSOCIATED WITH COOLING TOWER BLOWDOWN FOR TDS AND SO_4

	Scenario						
River	2	2a	2b	5	3	4	1
Illinois	TDS*[42]-25[43] SO_4-25	(2)[44]	TDS*-25 SO_4-25	TDS*-10 SO_4-10	TDS*-10 SO_4-10	TDS-10 SO_4-10	TDS-10 SO_4-10
Big Muddy	TDS-10 SO_4*-10	(2)	(2)	(2)	(2)	(2)	(2)
White	[45]						TDS-10 SO_4-10
Wabash	TDS-10 SO_4-10	(2)	(2)	(2)	(2)	(2)	TDS-10 SO_4-10
Big Sandy	-	-	-	-	-	-	TDS-25 SO_4*-25
Scioto		TDS-10 SO_4-10					
Muskingum	TDS-10 SO_4-10	TDS-10 SO_4-10	(2)	(2)	(2)		
Whitewater							TDS-10 SO_4-10
Beaver	TDS-10 SO_4-10	TDS-25 SO_4-25	(2)	(2)	(2)		
Allegheny	TDS-25 SO_4-10	TDS-25 SO_4-10	TDS-25 SO_4-25	TDS-25 SO_4-10	(5)	SO_4-10	SO_4*-25
Monongahela	TDS-10 SO_4-25	(2)	(2)	(2)	(2)	(2)	TDS-10 SO_4-25
Ohio	TDS-10 SO_4-10	TDS-10 SO_4-10	TDS-10 SO_4-10	TDS-10 SO_4-10	TDS-10 SO_4-10		TDS-10 SO_4-10

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[42] * Indicates new violations of the reference standard.

[43] The number 25 (or 10) indicates that the increase in concentration is more than 25% (or 10%) of the reference standard.

[44] (2) Indicates that this scenario is identical to the scenario indicated, Scenario 2 in this case.

[45] - Indicates that there is no planned or conjured plant capacity.

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The greatest increases in TDS in the Ohio River would occur under Scenario 2b, as discussed in Section 7.5.2.3. In that scenario the largest increase in the concentration of TDS in the Ohio River would be 35 mg/l if only power consumption is taken into account. The increase would be 79 mg/l if plant loadings are also considered. (If projected M & I consumption is subtracted from the base flow, then the maximum increase would be 84 mg/l as a result of plant consumption and loadings.)

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EPA-287 (Cin.)
(4-76)

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(4-76)